A COMPILATION OF 2020-2021 GLOBAL FLOOD EVENTS AND INTERNATIONAL EXPERIENCE IN FLOOD MANAGEMENT

IWHR 中国水利水电科学研究院
China Institute of Water Resources and Hydropower Research

ICFM

Flash Flood Program

CONTENTS

Preface

Currently, around 2 billion people worldwide are facing flood risk, of which nearly 600 million live in poverty. According to the Human Cost of Disasters issued by the United Nations Office for Disaster Risk Reduction (UNDRR), there were 3,254 recorded floods events worldwide from 2000 to 2019, the most common type of natural disaster that accounted for 44% of total disaster events. They affected 1.65 billion people, claimed about 100,000 death, and caused economic losses of up to 651 billion U.S. dollars. Compared with the past 20 years, the frequency of global floods in 2020 increased by 23%, with 201 floods killing about 6,200 people, based on the Center for Research on the Epidemiology of Disasters (CRED) in Belgium. Western Europe, East Africa, South Asia, and China were affected to a larger extent. The frequency and severity of floods increased due to climate change in the past few years, yet the risk of floods has been underestimated, resulting in huge casualties and property losses. The government should adopt a resilient approach to flood events and continue to disseminate the notion of flood management.

In an effort to propose countermeasures by reviewing 2020-2021 global extreme flood events, a series of international academic webinars were jointly convened by China Institute of Water Resources and Hydropower Research (IWHR) along with the International Conference on Flood Management (ICFM), and organized under the Flash Flood Program initiated by IWHR and Université Côte d'Azur (UCA). Renowned experts from various countries were invited to discuss and share experience and practices of flood management. Topics touched upon flooding in a time of pandemic, flash floods, ice-jam floods, urban flood forecasting, and resilience to flooding, etc.

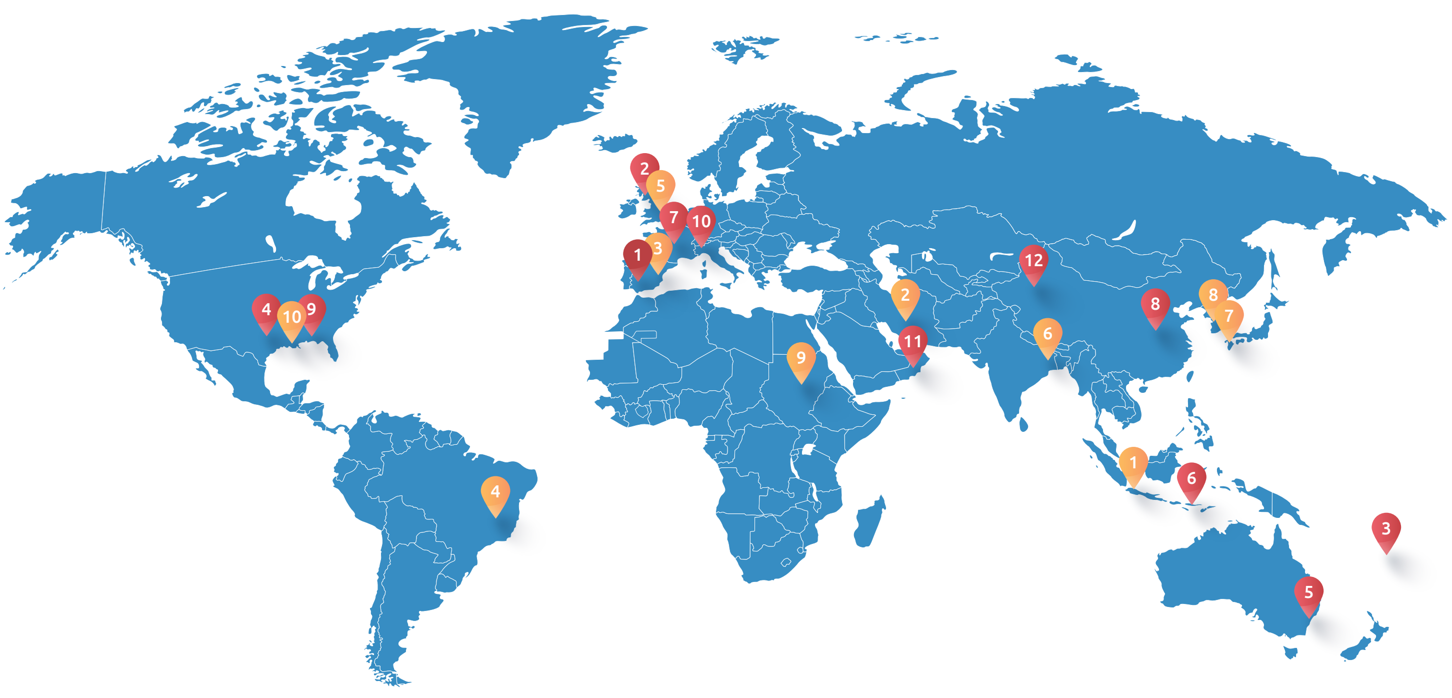
This report provides an overview of the global extreme flood events in 2020-2021, and extracts the outcomes presented at the webinars, in a way to offer an international reference and scientific support for global flood-related sectors.

Editorial Group
May 2022

A Review of 2020-2021 Global Flood Events

Climate change is causing an increase in the severity and frequency of extreme weather events that have taken millions of lives in the past 50 years. Referring to the 6th Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) released in August 2021, climate crisis is "unequivocally" caused by human activities, so it is necessary to keep reducing greenhouse gas (GHG) emissions and mitigating the impact of extreme climate-related disasters. This section is a review of extreme flood events on a global scale from 2020 to 2021.

Distribution map of global extreme flood events from 2020 to 2021



Global extreme flood events in 2020   Global extreme flood events in 2021

2020

1 Deadly flash floods in Indonesia

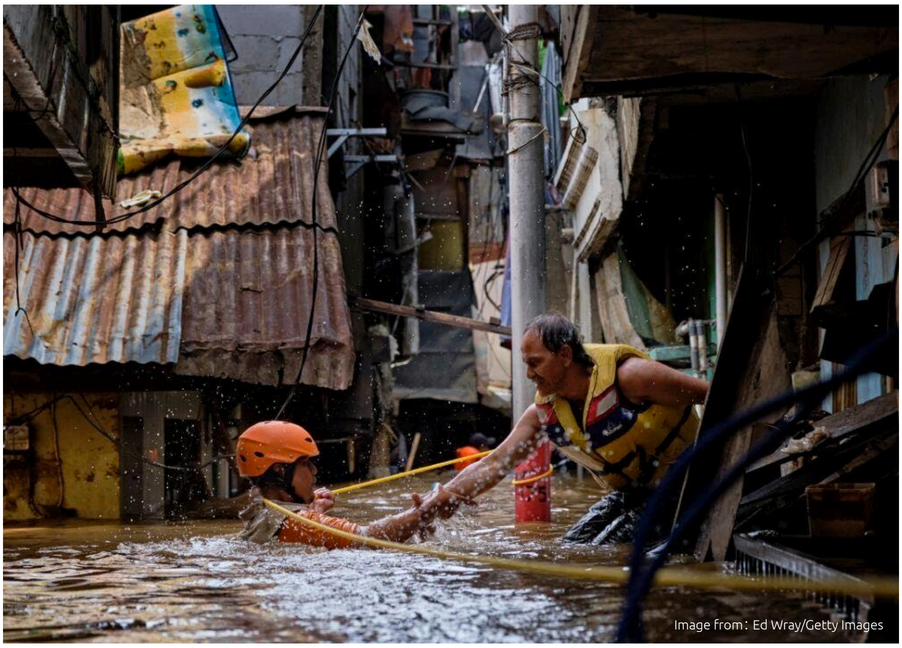


Image from: Ed Wray/Getty Images

In January 2020, flooding caused by record-breaking amounts of rain (337mm/24h) left at least 66 people dead and tens of thousands displaced from their homes in Jakarta, the capital of Indonesia, which has nearly 40% of the land that below sea level.

2 Disastrous floods in Iran

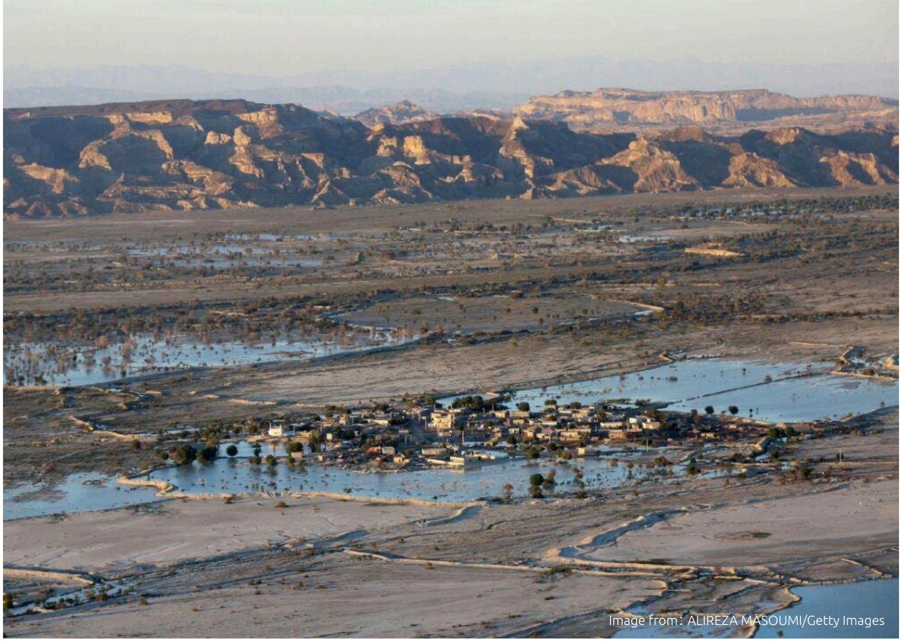


Image from: ALIREZA MASOUMI/Getty Images

On January 13, 2020, rainwater covered the village of Dashtiari as floods ravaged Iran's Sistan-Baluchistan region. The severe downpours led to floods across the entire area, blocking nearly 900 roads, cutting off electricity in 877 villages, and damaging homes and irrigation canal networks. More than 200,000 people were directly affected, public facilities and agricultural losses amounted to US$ 100 million.

3 Storm Gloria in Spain

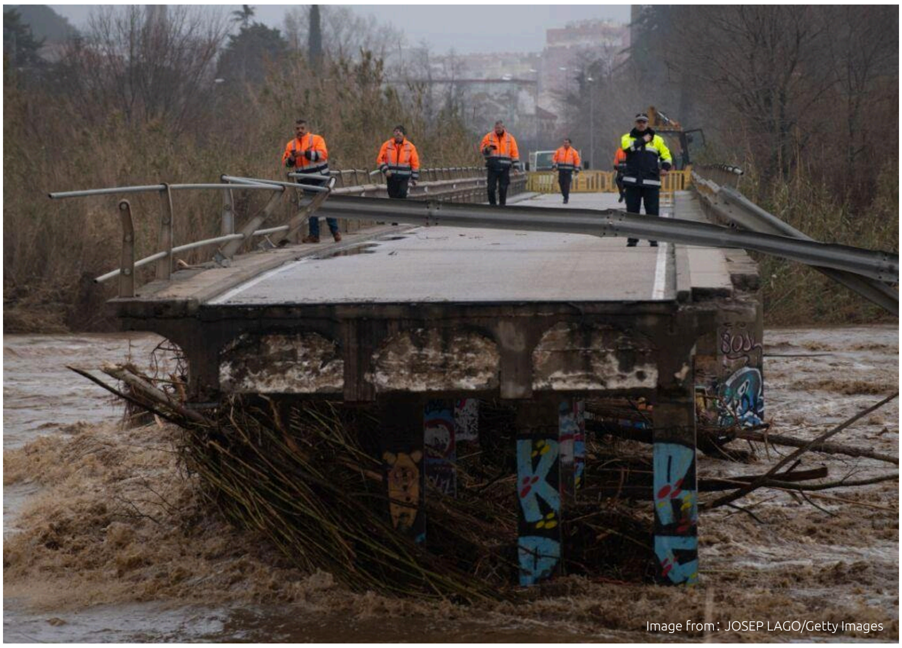


Image from: JOSEP LAGO/Getty Images

In January 2020, Storm Gloria cut off Spain's road and railway networks. It packed wind gusts of over 60 mph(96.6 kph), heavy snowfall, freezing rain, and massive waves that smashed into seafront promenades and damaged shops and restaurants. At least 220,000 homes were left without power, with at least 4 claimed deaths.

4 Catastrophic rain, landslides, and flooding in Brazil

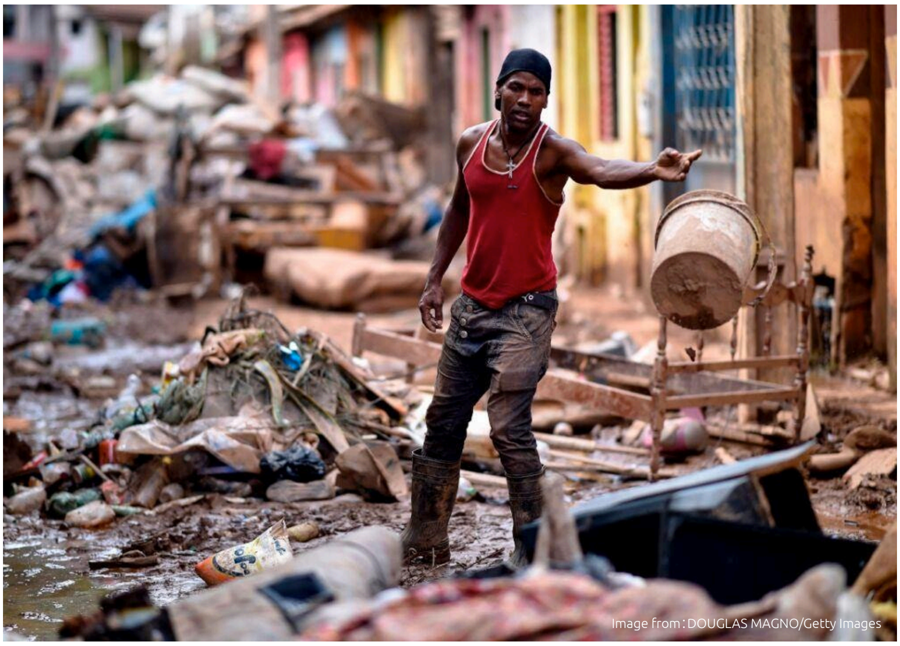


Image from: DOUGLAS MAGNO/Getty Images

On January 28, 2020, the picture shows that a resident managed to clear up rubble following the overflow of the Da Prata stream due to torrential rains in Raposos, a metropolitan region of Belo Horizonte, Minas Gerais state, Brazil. According to local civil defense officials, the death toll from days of intense storms and flooding in southeastern Brazil rose to 59, while 12 were injured.

5 Storm Dennis attacked the United Kingdom

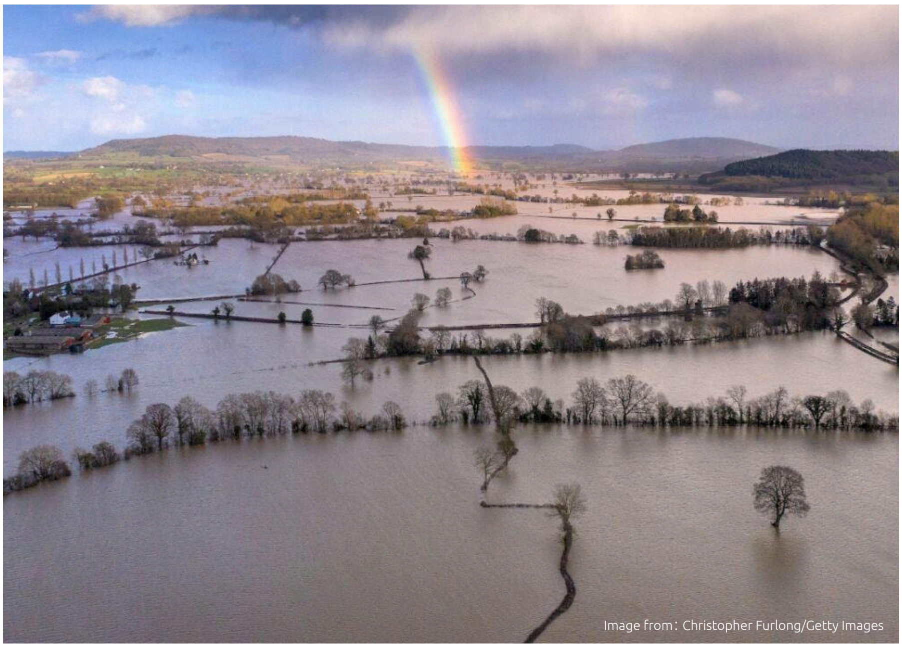


Image from: Christopher Furlong/Getty Images

On February 15, 2020, Storm Dennis swept across the United Kingdom at a speed of 91 mph (146 kph), triggering weather and flood warnings in multiple locations, with some of the areas being flooded. Finland and France also suffered the impact as tens of thousands of homes were left without power, 170 flights were canceled, and at least 5 people killed. Storm Dennis was the second named storm followed the aftermath of Storm Ciara, bringing extreme weather to England for a week.

6 Cyclone Amphan devastated India and Bangladesh

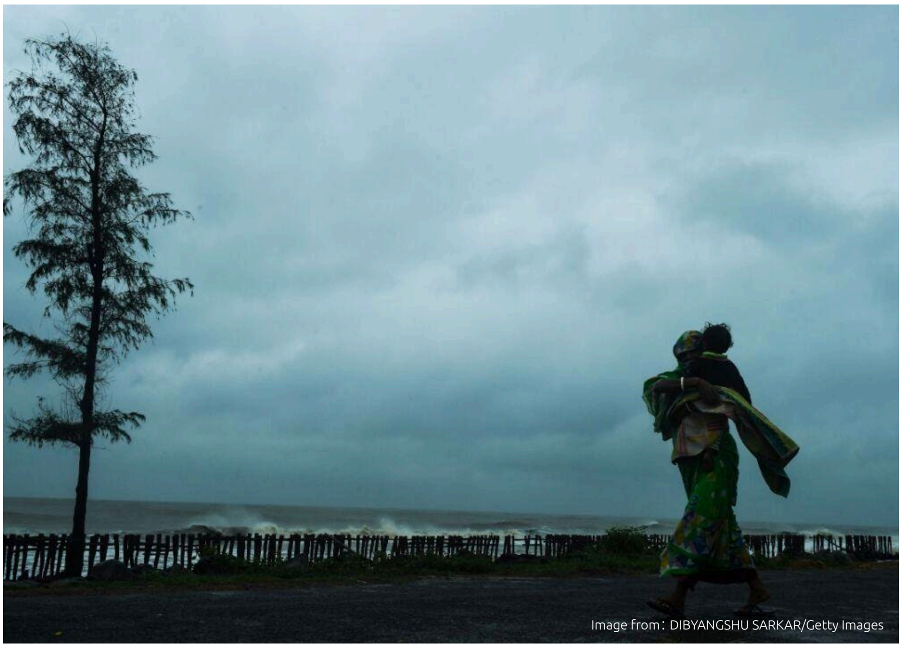


Image from: DIBYANGSHU SARKAR/Getty Images

On May 20, 2020, Cyclone Amphan ripped through West Bengal in eastern India and neighboring Bangladesh after its landfall in eastern India, causing 102 deaths and 4.9 million displacements. Ensuing strong gust and heavy rainfall in these areas toppled trees, damaged crops and orchards, and cut off transportation, power supply, and communication facilities, resulting in economic losses of 13 billion U.S. dollars. Cyclone Amphan that roared toward Bangladesh and eastern India with devastating and deadly storm surges was the Bay of Bengal's fiercest cyclone in decades.

7 Floods and landslides in Japan

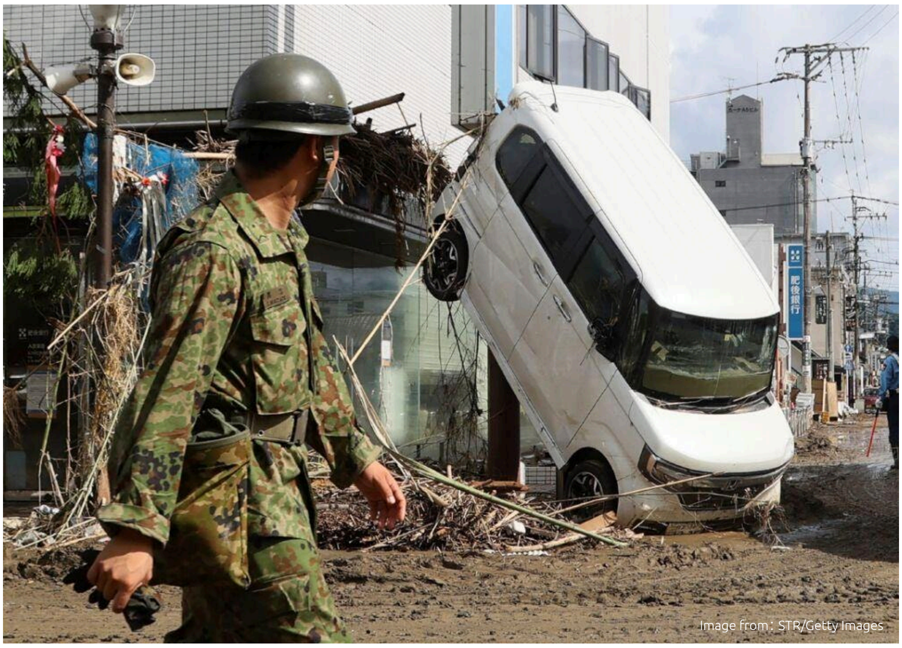


Image from: STR/Getty Images

In July 2020, around 14 rivers flooded seven prefectures due to torrential rainfall in Kyushu, Japan. Floods, landslides, and mudslides occurred in Kumamoto and Kagoshima prefectures caused power failure of more than 6,000 homes in Kumamoto Prefecture, 11 dikes along the Kuma River were at risk. These disasters took 77 lives, destroyed or damaged more than 15,000 buildings in Kyushu.

8 Deadly flooding in South Korea

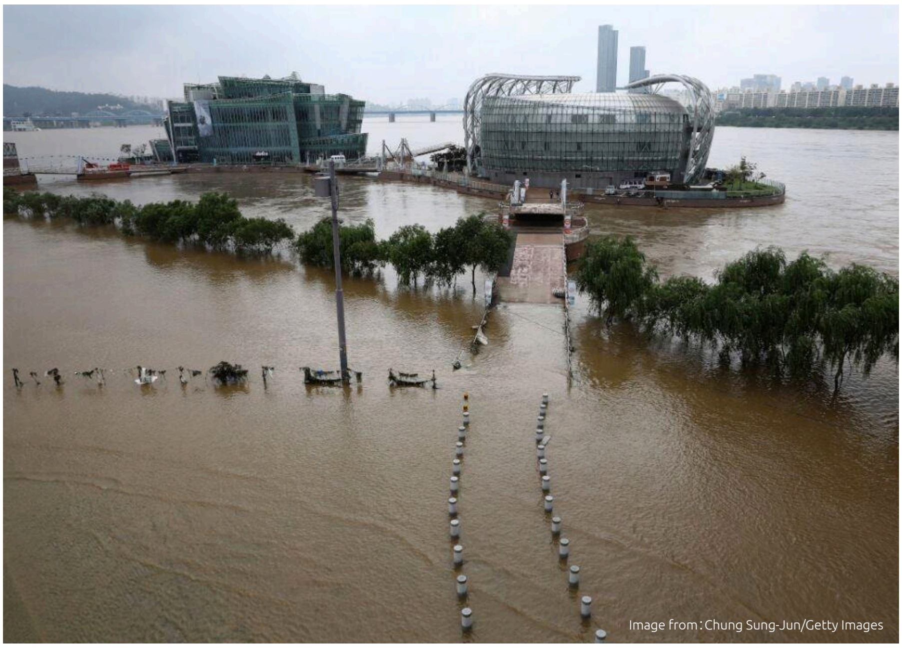


Image from: Chung Sung-Jun/Getty Images

In August 2020, damage from heavy rain that pounded the central region of South Korea for 46 days, the longest monsoon in the area since 2013, killed at least 26 people and left more than 1,000 displaced from their homes. As shown in the picture, the flooded Han River Park was seen after torrential rain on August 4, in Seoul.

9 Widespread flooding in Sudan

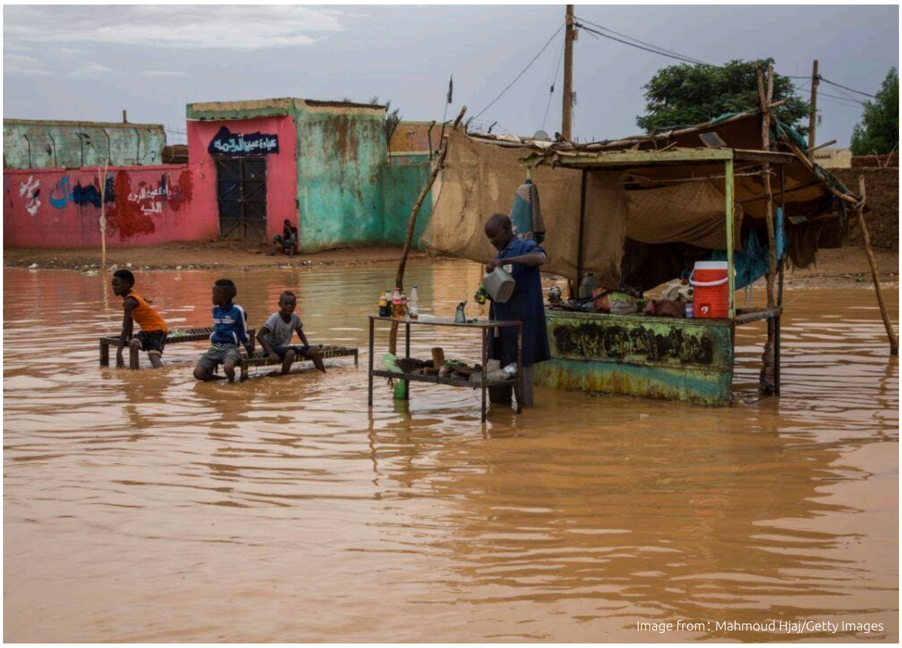


Image from: Mahmoud Hjaj/Getty Images

On September 8, 2020, heavy rain caused flooding in Khartoum, the capital of Sudan. The death toll reached almost 100, more than 100,000 homes were damaged, with over 650,000 people affected. Water levels of the Nile River and some of its tributaries rose to heights never seen in the past 100 years, with the Nile River hitting a record high of 57 feet (17.4 meters). The picture presents that children were taking refuge in a flooded street after heavy rain hit Khartoum.

10 Hurricane Delta hit the Gulf Coast

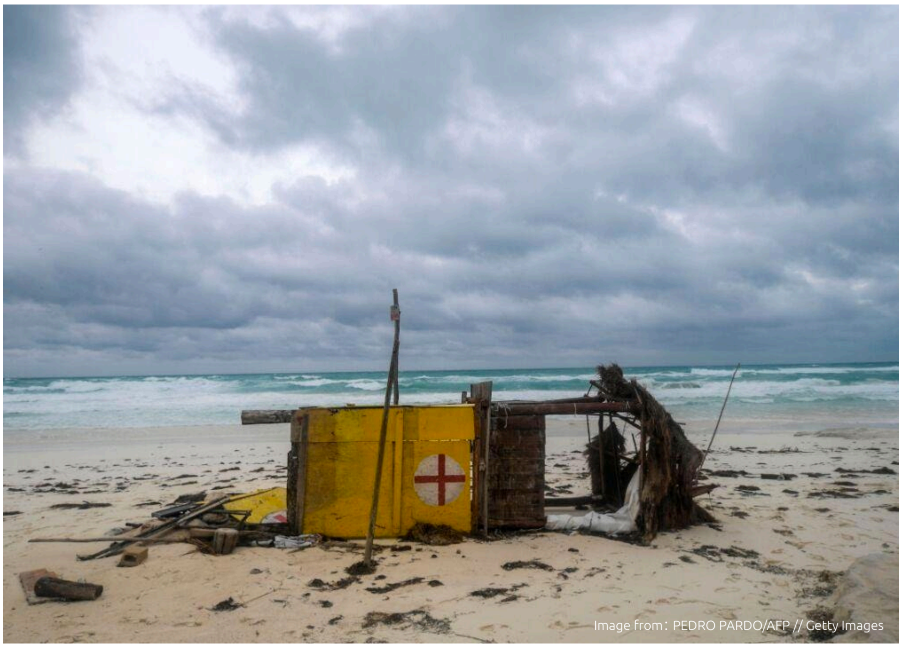


Image from: PEDRO PARDO/AFP // Getty Images

Hurricane Delta made landfall in Creole, Louisiana at 7 p.m. EDT on October 9, 2020, packing 110 mph (175 kph) winds. It caused approximately 700 million-1.2 billion U.S. dollars insured losses in wind and storm surge, and an additional 800 million-1.5 billion U.S. dollars losses in offshore structures. It was the second storm in six weeks to slam Louisiana—Hurricane Laura visited at the end of August, 2020.

References: https://stacker.com/stories/4621/2020-climate-disasters-50-photos?page=3

2021

1 Record-breaking snowfall in Madrid, Spain

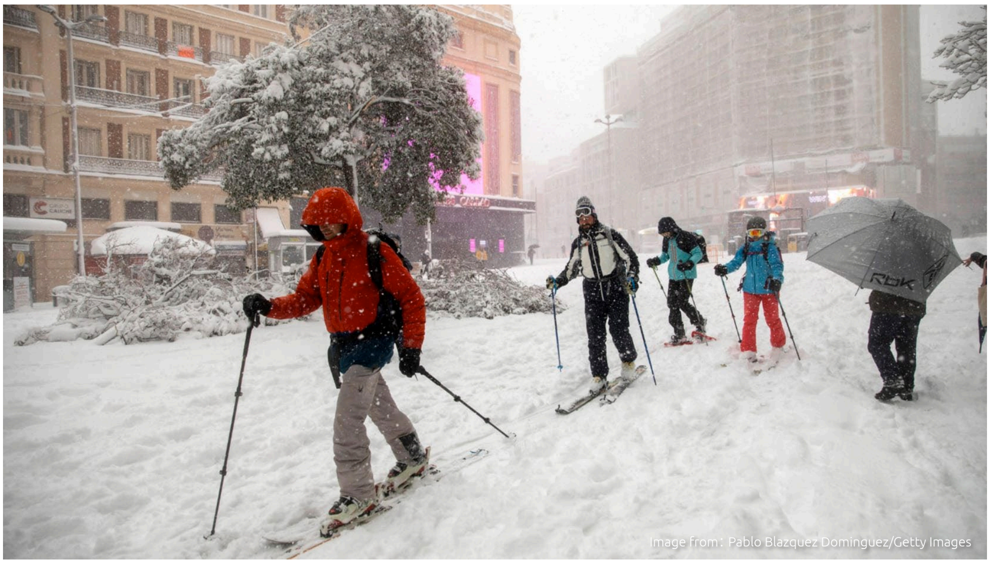


Image from: Pablo Blazquez Dominguez/Getty Images

In the first week of 2021, Storm Filomena brought record-breaking levels of snow to Madrid, elderly Spanish citizens were warned to stay at home as temperatures plummeted. As Euronews reported, this heaviest snow in 50 years brought transportation in and out of the city to a standstill. The snowstorm caused around 1.4 billion eruos of damage, The New York Times said.

2 Storm Christoph in the United Kingdom

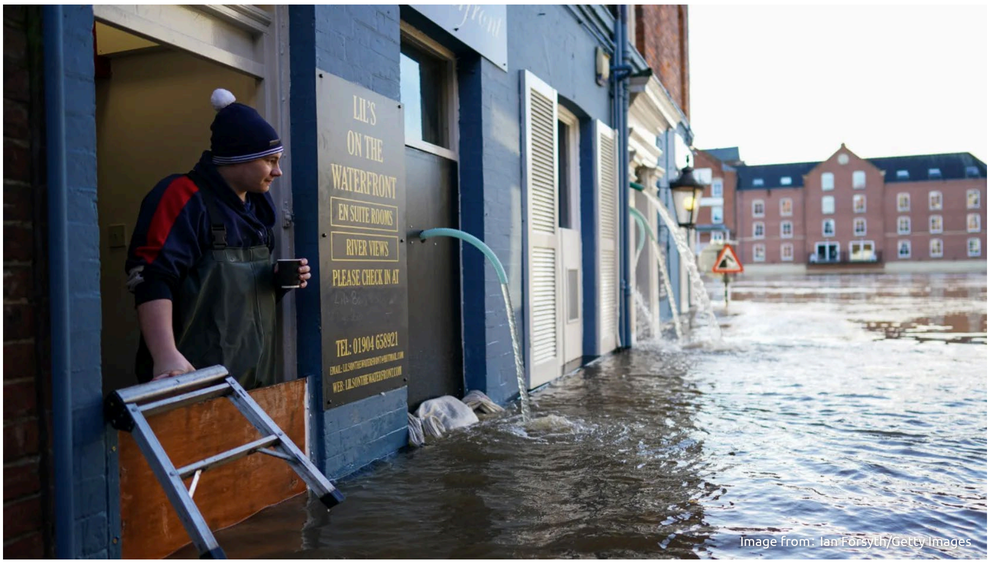


Image from: Ian Forsyth/Getty Images

The period from January 18 to 20, 2021, was "one of the wettest three-day periods on record" for North Wales and North-West England, according to the UK Met Office. Homes in Cheshire were flooded, and residents were evacuated from homes in Manchester and Merseyside. Once Storm Christoph cleared, significant snowfall also led to travel disruption with icy conditions and road closures.

3 Cyclone Ana in Fiji

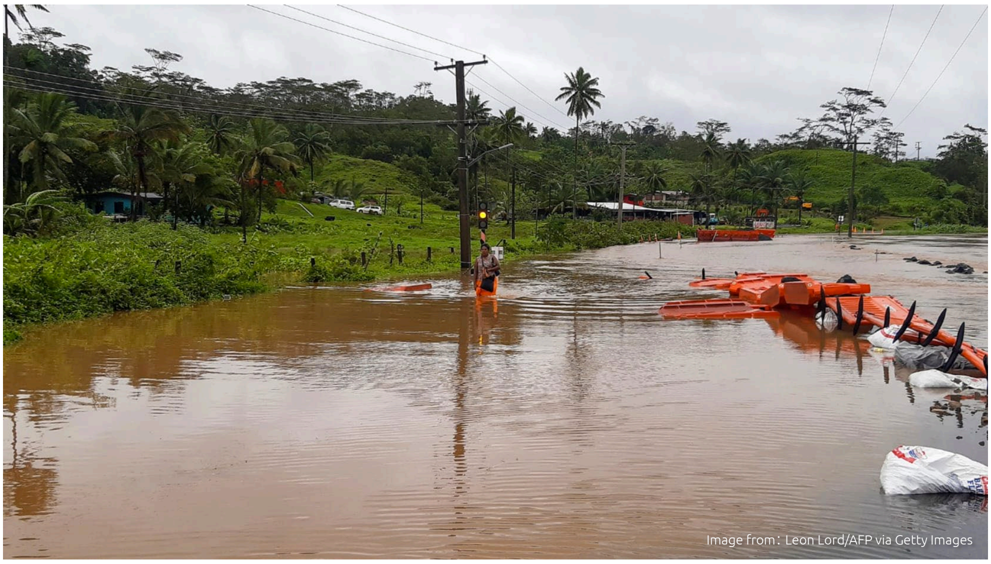


Image from : Leon Lord/AFP via Getty Images

Cyclone Ana "pummeled" Fiji towards the end of January 2021, "just a month after Category 5 Cyclone Yasa tore through the country's northern islands", The Guardian said. It caused more than 10,000 people to take refuge in 318 evacuation centers across the country.

4 Winter storms in Texas, the United States

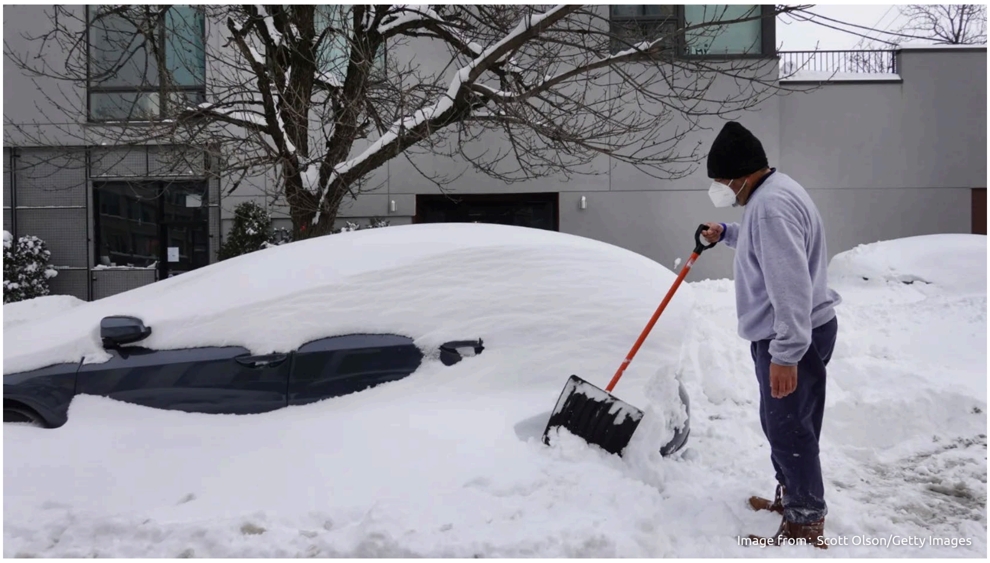


Image from : Scott Olson/Getty Images

Around 3.5 million businesses and homes were left without power in February 2021 while temperatures dropped to -13°C in some areas of Texas, The Week US reported. Power went out across the state, leaving many vulnerable communities in extremely cold conditions. The total death toll rose to 210 in July 2021, after a decision was made to include deaths caused by the collapse of the state electric power grid in the final count, The Guardian said.

5 Flooding in New South Wales, Australia

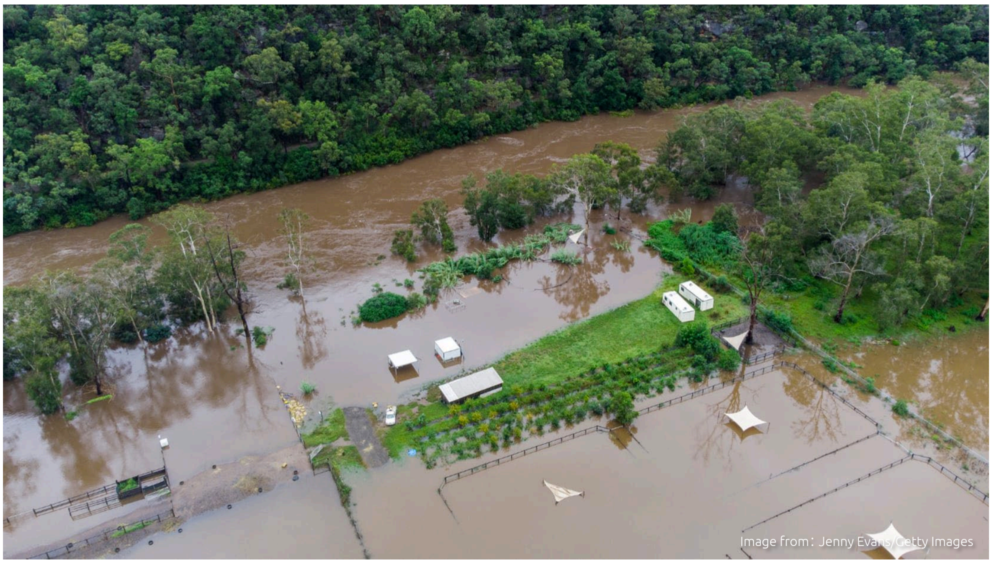


Image from: Jenny Evans/Getty Images

In March 2021, residents of New South Wales in southeastern Australia suffered from the worst flooding in 50 years. Heavy downpours, beginning on March 18, led to rivers and dams overflowing, with about 18,000 residents evacuated from their homes.

6 Cyclone Seroja in Indonesia

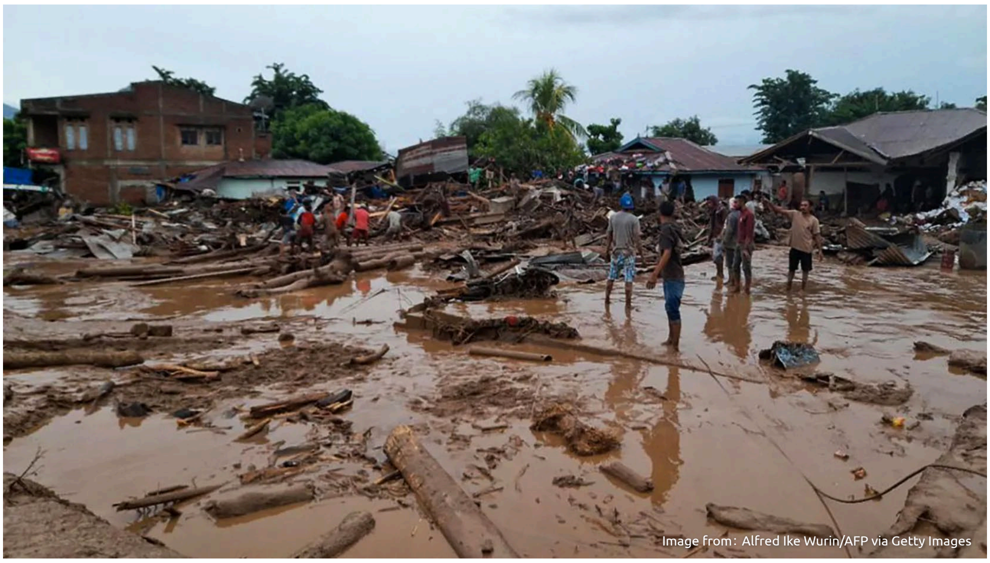


Image from: Alfred Ike Wurin/AFP via Getty Images

In April 2021, 160 people died in Indonesia after cyclone Seroja "hit a remote cluster of islands", Climate Home News reported. Landslides and flash floods displaced at least 20,000 people.

7 Extreme flood in west Germany

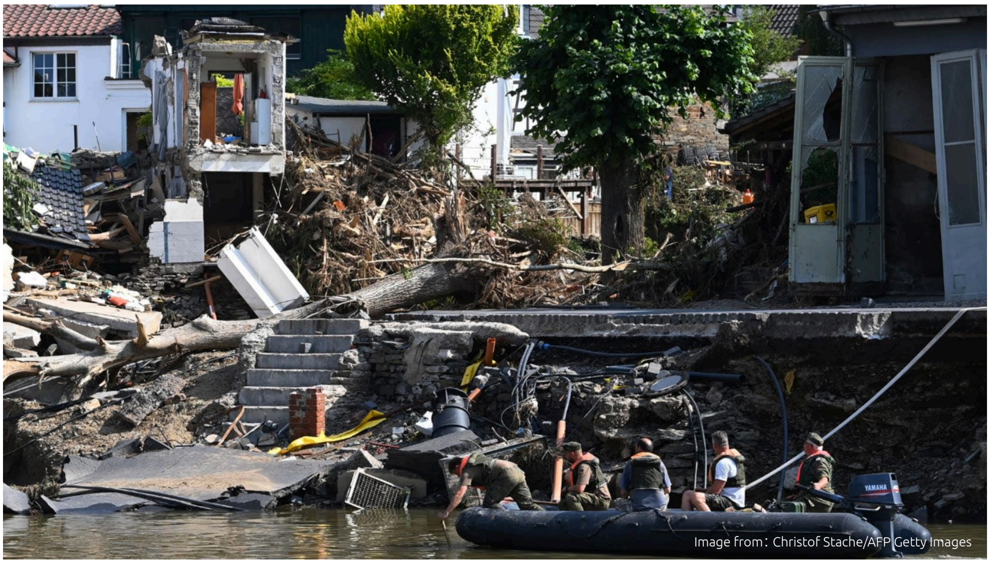


Image from: Christof Stache/AFP Getty Images

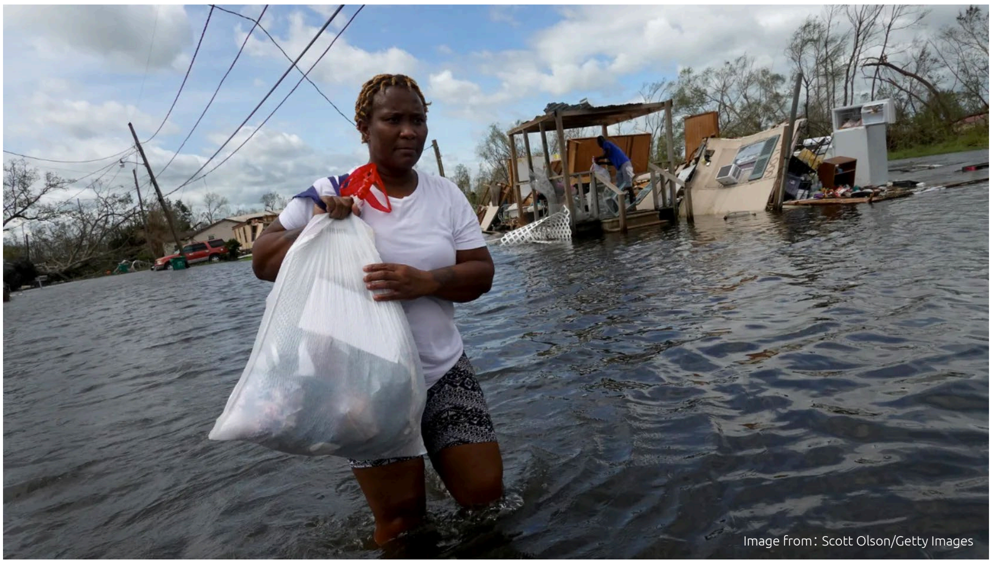
In July 2021, a 100-year flood stroke Germany as rains lasted for nearly 14 hours, eventually causing a loss of 10 billion euros and 181 deaths, according to CNN. The maximum precipitation reached 23.7 mm in one hour and 162 mm in 24 hours at the rainstorm center. This flood destroyed homes, bridges, and roads along the River Ahr. Euronews reported,victims would be supported by a government-approved 400-million euro recovery package as ministers have promised to move quickly on rebuilding affected areas.

8 Extreme rains in China


Image from: STR/AFP, Getty Images

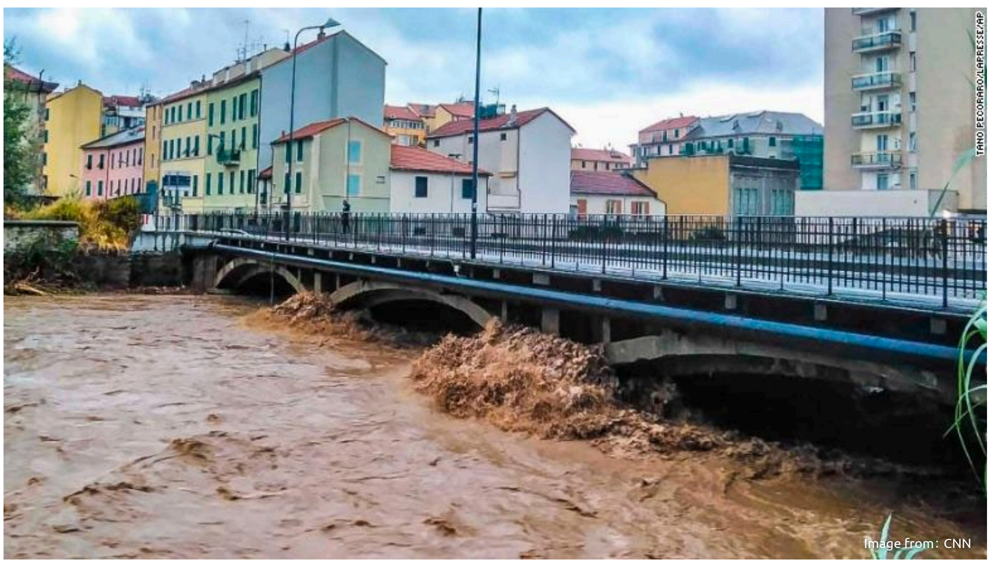
On July 18, 2021, extreme rains stroke Zhengzhou in Henan Province of China, with average total precipitation of 449 mm and record rainfall in local areas from 18:00 to 21:00, according to Zhengzhou Meteorological Service Center. In early October 2021, Shanxi Province in northern China, a region that used to have 9-year drought in 10 consecutive years, experienced a rare continuous heavy rainfall. A total of 59 national meteorological stations reported daily precipitation reaching record high as compared to the same period since their establishment, and 63 stations witnessed process precipitation exceeding the historical extremum of the same period.

9 Hurricane Ida in the United States



Hurricane Ida made landfall in Louisiana and Mississippi in the southern United States, on August 29, 2021, the 16th anniversary of Hurricane Katrina. More than one million homes and businesses were left without power after Ida hit with maximum sustained winds of 150 mph (240 kph). It was later downgraded to a tropical depression from Category 4 to Category 1, and moved along the northern-eastern coast of the United States. In New York, subway stations and roads were flooded, and at least 9 people were killed.

10 Tropical cyclone in Italy

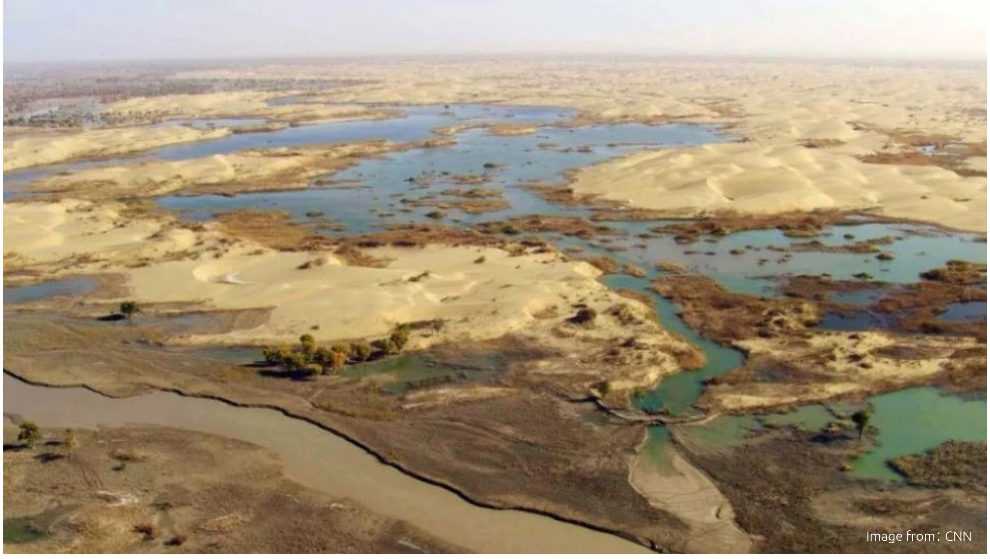


On October 4, 2021, a tropical cyclone smashed into northwestern Italy and unleashed over 742 mm of rainfall in just 12 hours, setting a new European mark on record, CNN reported. Floods and mudslides doted the affected area due to downpours in a very short period.

11 Cyclone Shaheen in Oman

On October 4, 2021, Cyclone Shaheen dumped extreme rains in Oman on the Arabian Peninsula, bringing floods to the normally parched city of Al Khaburah. The cyclone made landfall in northern Oman with winds just shy of a Category 1 hurricane, and produced more than 300 mm of rainfall in a matter of hours, which is the equivalent to more than three years' worth of rainfall in about 24 hours.

12 Flood in the Taklimakan Desert

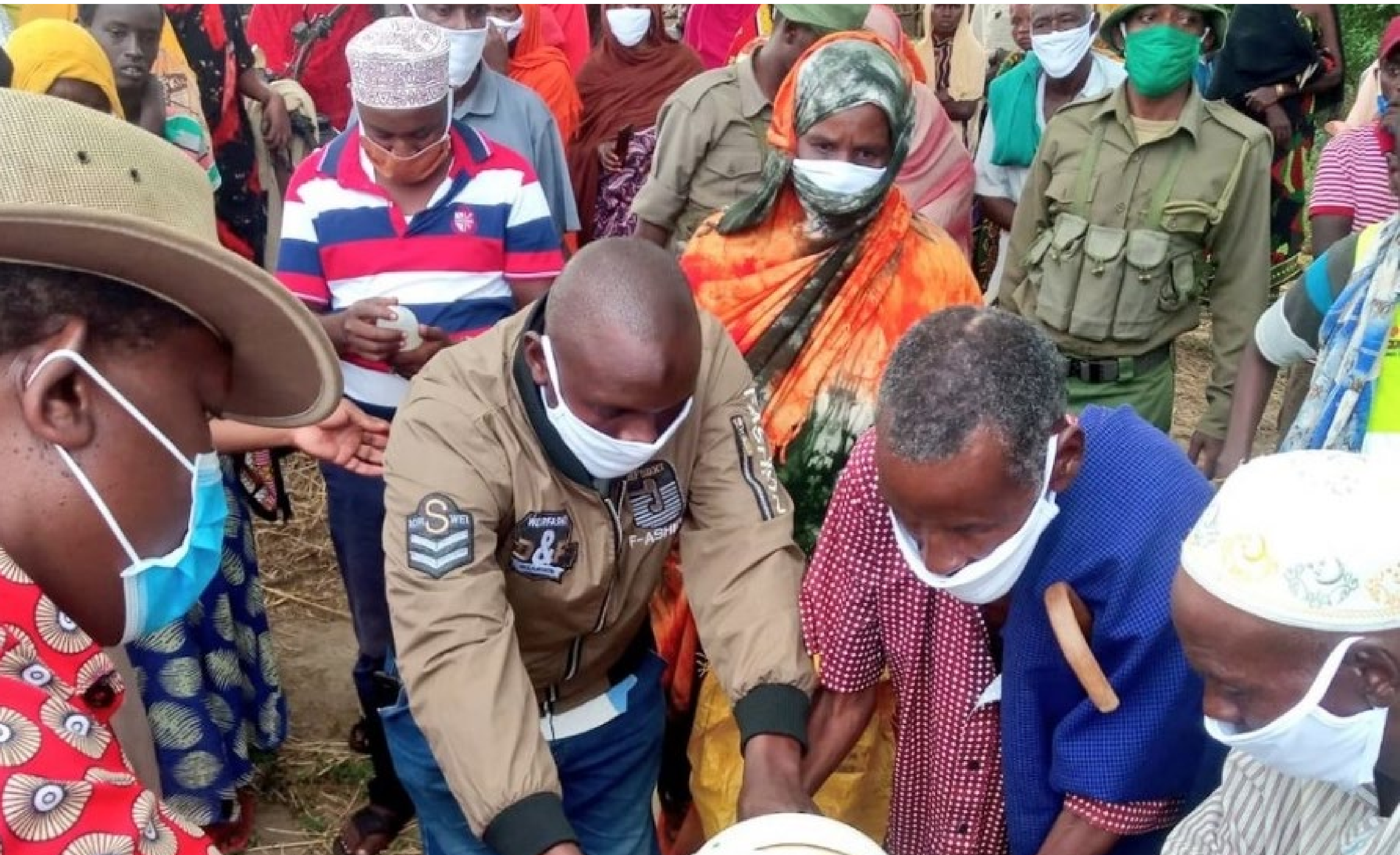


In July 2021, a rare flood hit the Yuqi area of Sinopec Group's Northwest Oilfield in northern Taklimakan Desert, with the flooded area of more than 300 square kilometers. Roads in the oil area were washed away, telegraph poles inclined, nearly 50 exploration vehicles and 30,000 sets of equipment were inundated. The flood is mainly caused by heavy rain in the Dinaer section of the Tianshan Mountains in Luntai County since late July 2021, in addition to melting snow in the Tianshan Mountains during summer.

References: https://www.theweek.co.uk/news/environment/953574/worlds-most-extreme-weather-events-2021

Doubled Crises—Flooding in a Time of Pandemic

On May 28, 2020, the Secretariat of ICFM, hosted by IWHR, invited 4 distinguished experts to conduct a discussion on flood management in face of the COVID-19 pandemic. The panelists include ICFM Chairperson,Prof. Slobodan P. Simonovic from Western University, Canada; Prof. Zbigniew Kundzewicz, member of the Polish Academy of Sciences, Poland; Prof. Cheng Xiaotao, Senior Engineer of IWHR, and Editor-in-Chief of the Journal of Hydraulic Engineering, China; and Prof. Nigel G. Wright from Nottingham Trent University, the United Kingdom.



Slobodan P. Simonovic

ICFM Chairperson, Water Resources Specialist, Institute for Catastrophic Loss Reduction, Western University, Canada

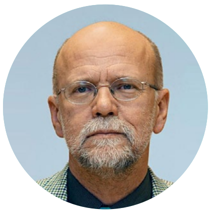
Doubled Crises—Flooding in a Time of Pandemic

"The coronavirus outbreak remains a global health crisis affecting our well-being and the world economy. As for us, the full impact of COVID-19 on the management of floods will not be known for quite some time. Still, we would like to better understand its short- and long-term effects on flooding," said Prof. Simonovic.

Prof. Simonovic pointed out that, the world is experiencing a multihazard problem—flooding in a time of pandemic—through a few examples, including the floods in East Africa, the dam breach in Michigan, the tropical cyclone in India, the heavy rain and flood in Guangdong Province of China. Based on the analysis, he proposed a cause-effect chain of such doubled risks: epidemic→ reduction of infections → flooding → evacuation → increase of infections. Since social distancing or self-isolation is adopted during the epidemic, collaboration is needed to deal with flooding, Prof. Simonovic mentioned. In countries with inadequate medical resources, close contact increased the risk of infection. Despite the outbreak of the pandemic has caused direct economic losses, more resources still need to be mobilized for flood rescue and recovery.

In response to these compound risks, Prof. Simonovic highlighted that people need to fully understand the significance and uncertainty of the risks and shift from risk control to risk management. For most countries, the departments in charge of pandemic and flooding are normally isolated. However, when two emergencies occur at the same time, these two or more departments are required to coordinate and cooperate to cope with challenges, which is a new issue for us. Pandemic and flooding are constantly influencing each other and give rise to many new problems, a thorough understanding of these problems and their interaction is fundamental to building emergency response capacity. As many Canadian media stated, this seems to be a "nightmare scenario" for emergency managers: two potentially serious emergencies happening at once. In most places, flood control and disease control departments used to perform emergency management independently and based on experience. In the event of such coinciding crises, there might be a lack of communication among these departments, which may lead to a neglect of the priorities during the emergency response and the economic losses caused by the doubled crisis.

Prof. Simonovic also made comments on how to use the system approach in risk evaluation, he stressed the importance of scientific simulation of risks. The system approach is helpful when understanding the entire system, and the interactions among each component. In turn, the interactions continue to shape the behavior of the system—which refers to the mutual impact brought by the coincidence of epidemic and flooding in this case. Prof. Simonovic mentioned that this approach could be used to predict the behavior, that is, the hazard of epidemic and flooding, and to evaluate corresponding emergency measures. Also, natural sciences, social sciences and engineering may be integrated into the overall framework, in a bid to facilitate the analysis of and response to the current situation.



Zbigniew Kundzewicz

Hydrologist, Polish Academy of Sciences, Poland and Nanjing University of Information Science and Technology, China

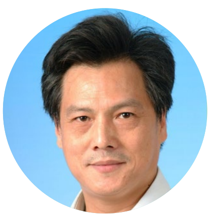
Flood-risk Projections in a Multi-risk Context

Projection is the basis and guarantee for risk management and has gained more global attention. Prof. Zbigniew Kundzewicz from the Polish Academy of Sciences gave an overview of 2020 flood events worldwide in the COVID-19 context. According to statistics, flood events occurred in about 30 countries after the detection of the first COVID-19 case, resulting in a considerable number of the displaced populations. For instance, the Sardoba Dam collapse on May 1,2020, cased huge loss in Uzbekistan. The Sardoba Dam is located in the Syr Darya region in eastern Uzbekistan. Completed in 2017, the dam can impound 922 million m^3 of water, being the main resource for local agricultural irrigation. Heavy rains and stormy winds on May 1 caused a dam wall to collapse partially, flooding a large area of land in both Uzbekistan and Kazakhstan. Around 70,000 people in Uzbekistan and over 31,000 people in Kazakhstan were evacuated. During the process of relocation, practicing social distancing was almost impossible for residents living in areas with a higher risk of COVID-19, thus exacerbating the risk of infection to a certain extent. Therefore, the way of relocating people safely after flood disasters amid the epidemic is a new problem that has not been experienced or considered before.

In the context of climate change, predictive research on the nexus between climate variability and flood damage has been in the spotlight. Based on his research findings, Prof. Kundzewicz believed that compared to the historical conditions from 1900 to 1970, the runoff of ice-free land in many regions of the world is estimated to change drastically by the middle of the 21st century (2041–2060) under certain climate scenarios. The frequency of heavy precipitation or its proportion of total rainfall will likely increase over many areas of the globe.

Other latest research outcomes were shared during the discussions. Flood risk in most parts of the world may increase in the context of global warming. When interpreting changes caused by the combined effect of economic and climatic conditions, his research team predicted that flood losses in China are projected to soar in the future, particularly in lowland regions experiencing rapid economic growth.

On how rescuers can accurately identify signals and take prompt actions for residence transfer and material evacuation during flood events, Prof. Kundzewicz pointed out that the actual situation may be more chaotic because it is difficult to accurately distinguish the signals. As said above, due to the Sardoba dam failure in early May, more than 100,000 people were evacuated on a large scale within Kazakhstan and Uzbekistan, including residents from high-COVID-19-risk areas. The risk of infection increased during this process because it was difficult to follow the epidemic prevention rules and maintain social distancing. Therefore, we need to find a way to remind ourselves of some potential risks from time to time. The European Commission has set a good example by requiring the 27 member states to comply with the EU Floods Directive and to stay alert for flood hazards whether they are in flood season or not. We should overcome short-term memory of catastrophic events and think more about how to deal with low-probability and high-risk events in the long run—such as the worldwide pandemic and extreme floods.



Cheng Xiaotao

Flood Specialist, China Institute of Water Resources and Hydropower Research (IWHR), China

Beware of Catastrophic Flood Events with Properties of Black Swan in the Midst of COVID-19 Spreading around the World

In most people's view, the COVID-19 pandemic is no doubt the Black Swan of 2020. The lessons we have drawn from this Public Health Emergency of International Concern (PHEIC), which has evolved into a social and economic crisis with far-reaching impacts, were painful and profound, said Prof. Cheng Xiaotao. Given the sharp declines in the first 4 months of the COVID-19, the economy will surely be overwhelmed by another blow of the potential flood. Therefore, it is necessary to make decisions and plans ahead, to turn the threats into our favor and provide strong support to the earliest recovery of the society and the economy.

Every major sudden disaster, accident, or event always has the stages of incubating, outbreaking, spreading, and subsiding. Despite that their roots, forming mechanisms, spreading modes, and coping measures vary, all of them must be handled with all-out efforts in risk prevention, monitoring and early warning, emergency responses, relief and resettlement, and recovery and restoration, and with flexible tactics that are positively responsive to the actual situations. Any negligence or delay at any point would bring trouble to the following works, or even lead to irreversible losses or damages. For the Black Swan events, which rarely occur but usually lead to disastrous consequences, the key lies in whether the precursory signals and real-time information can be closely traced, constantly updated, and promptly reported to responsible departments from the front line; whether the possible scale and severity of the disaster can be anticipated in a quick, fact-based and rational manner; and whether the coping strategies and measures can be adjusted according to real situations. The point is to provide a transparent information-sharing mechanism to facilitate the multi-agency and coordination of governments and departments at all levels, and the active participation of grass roots organizations and the public.

The great changes in flood risk features in China have increased the complexity and toughness of flood prevention and disaster reduction, which means higher requirements for transforming the safety assurance in the face of flood risk mitigation. For China, the mega-flood in 1998 proves to be a turning point, from which the country accelerated the construction of a modern flood control system, making it capable of tackling regular floods and more confident in the face of major floods happening in the 20th century. However, as urbanization quickens and global warming worsens, significant changes have taken place in China in terms of the affected people, disaster-inducing mechanisms, disaster mode, and types of losses. Since 2010, despite that the rivers and lakes conditions have remained quite stable, the country still has seen severe flood-led losses up to 234.8 billion RMB each year, mainly caused by rainstorm-driven floods in urban areas, small and medium-sized river floods and flash floods. Additionally, due to the growing demand on the lifeline network system, such as the supply of water, electricity, gas, and transportation and telecommunications in modern society, plus the effects of industrial chains formed in the economic operations, the impact range of floods has gone far beyond the flooded area, and sometimes the indirect losses can even surpass the direct ones. In the meanwhile, for those less-developed areas where most young people have moved to cities for work and the transaction rate of land is higher, the capability of embankments maintenance and emergency rescue during flood seasons is weaker. For those big-specialized households of crop and animal production, who are dependent on the land transactions in the early stage of business and have borrowed money for building farming facilities, the floods can easily send them into heavy debt. On the other hand, these people are mostly the backbones of the local economy. If the disasters happen, the local economy would suffer even more, thus widening the development gap among regions.

Human have been capable of monitoring and forecasting floods, early-warning responses, and taking necessary prevention and control measures. To some extent, human have also been adaptable to floods. However, this is not necessarily true to the extraordinary floods, which bear the features of Black Swan events. With almost 100,000 reservoirs in China, even if several of them cause flood dangers per year, the probability is only less than 1 in 10,000; for its dikes that stretch more than 400,000 km, even there are hundreds of them broken per year, that also accounts for less than 1 in 1000 by accident rate per km. It should be noted that reservoirs and embankments of different grades adopt varying protection standards. Once extraordinary rainstorm floods happen, it would be impossible to make an accurate forecast on which engineering facility would fail. On the other hand, most of the administrative governors who command flood prevention lack field experience in handling real floods, let alone the disaster chains resulting from several different kinds of disasters, or the chain effects formed between lifeline systems. When these situations happen, relevant operating departments should be capable of making quick judgments through joint consultations based on the rainfalls, floods, front-line work, conditions and severity of the disaster, and promptly provide several optional deployment and command plans to avoid mistaken decisions.

Risk management and emergency management are the main threads that are mutually complementary in the construction of the public security protection system. In tackling the black-swan-type floods, decisions are usually made in the manner of "evaluating the dangers and picking the lighter one", thus it becomes rather difficult to ensure absolute safety. Being overly hesitant during critical moments may spoil the chance to win the battle, leading to more serious consequences. At the same time, we should realize that floods always come as a double-edged sword. For many places, one flood or two during the flood season remain the main source of water supply. Therefore, adopting the "zero risk" management policy may bring excessive costs for the flood control, throw the coping tactics out of balance, threaten the safety of food, drinking water, water supply, the economy and the ecology,thus hindering the economic recovery instead. In a word, the flood-prevention work in 2020 is rather complex and challenging. To tackle that, we must bear the risks with a strong sense of responsibility, enhance the inter-departmental multi-agency and coordination by mobilizing the forces of grass-roots organizations and the public, and adopting scientific strategies and targeted measures, to eradicate the risks and bring safety to the people.

Nigel G. Wright

Flood Specialist, Nottingham Trent University, UK

Resilience: Lessons from the Pandemic Response for Other Crises

Prof. Nigel Wright started with the basic concept of resilience to explain why a shift from defense to resilience is necessary. Even though it is rather difficult for us to completely prevent sudden-onset disasters such as flooding and virus, we may adopt some mechanisms and measures to reduce the likelihood and the impact. Resilience in the field of flood management refers to "the capacity of the whole system to reorganize while undergoing change in flood wave frequency and severity in the long term, so as to enable it to function normally" (Gersonius, Delft FRG, 2008).

Prof. Wright proposed to improve the emergency response system and the public understanding of risk for the shift from defense to resilience, in a way to better cope with complex situations of doubled or even multiple crises.

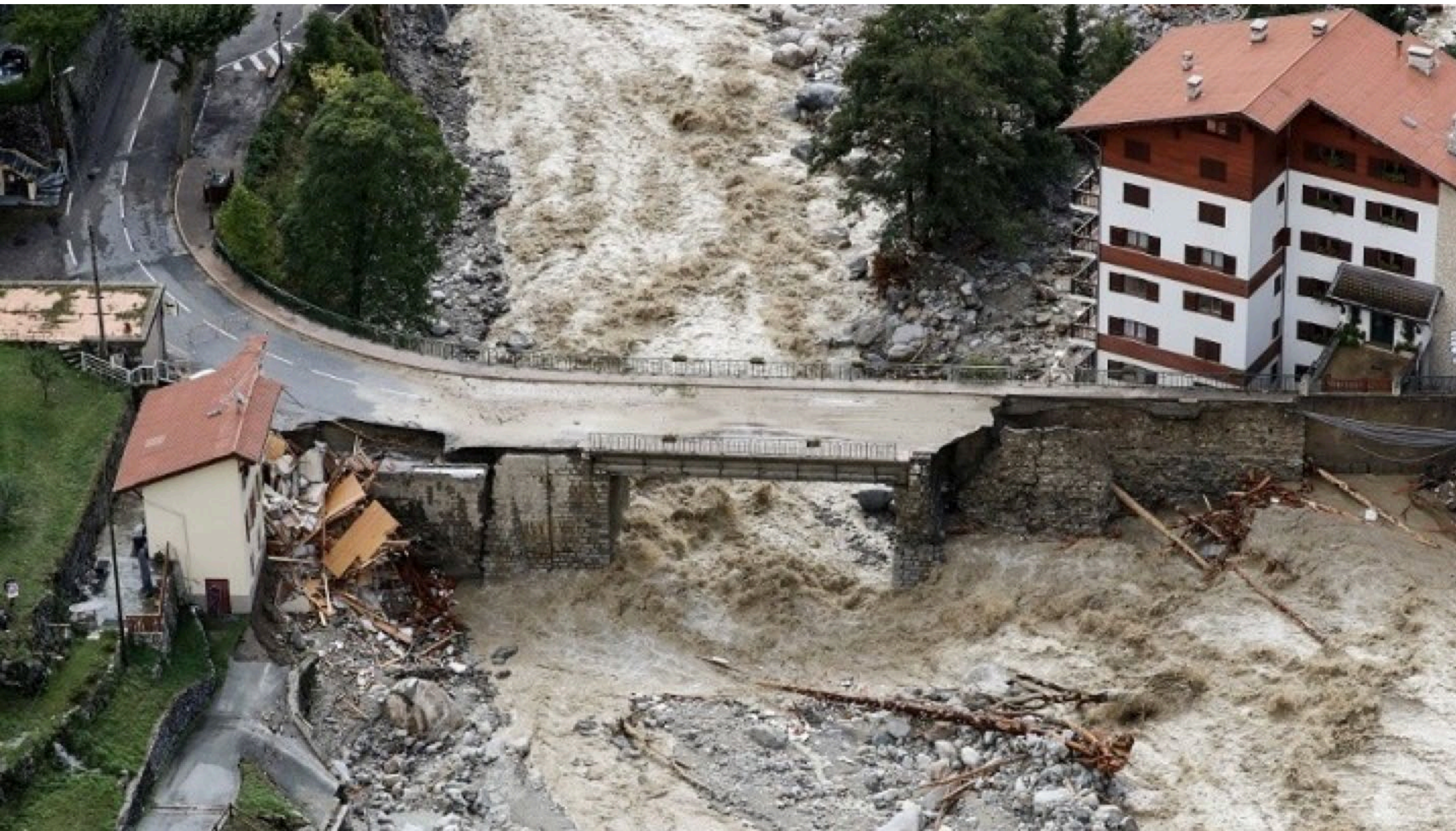
It seems that we will not return to the status quo we had before COVID-19, under the global new normal, we must adapt in active response to each disaster event in the future. To establish and improve the emergency response and management system, central control from the government should be combined with local autonomy. A fundamental change in how we view flood management is also required, that is, to live with and make space for water, also pay attention to spatial planning and learn to consider all forms of water as providing multiple benefits.

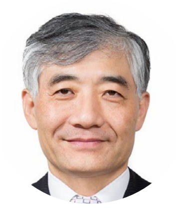
Public perceptions and attitudes to flood and COVID-19 risks vary across individuals. For example, as the virus is still widely spreading, some people are afraid and worried, but some turn a blind eye. A professor from the University of Cambridge estimated that the risk to children of catching and then dying from coronavirus in school is comparable to traveling to school in a car. So, what should we do to cope with disasters? On the one hand, it is necessary to have a scientific understanding of such disasters, and the other is to well prepare the mind and the plan in advance. For example, countries that had suffered from SARS (Severe Acute Respiratory Syndrome) and MERS (Middle East Respiratory Syndrome), such as China and South Korea, are better prepared for COVID-19, demonstrating that hindsight is important. A flood manager from the Netherlands once prayed: “God, gives us today our daily bread and a small flood from time to time.” In such areas where floods occur frequently, the mindset of preparing for floods has been common among local residents. As such, understanding public behavior and thoughts and raising public awareness of risks are the keys to improving resilience to disasters.

Prof. Wright added that under the new normal, disaster resilience can improve when the entire society has the capability of hazard resistance and mental protection against disasters. He emphasized that disasters have become more complex in the past few decades, thus requiring more interdisciplinary collaboration between social and natural scientists in response to possible complex disaster events in the future.

2020-2021 Flash Floods: Global Challenges and Lessons Learned

On September 7, 2021, a webinar themed "2020-2021 Flash Floods: Global Challenges and Lessons Learned" was hosted by IWHR and organized by the FFP Secretariat and the ICFM Secretariat. Three panelists introduced classic cases of extreme rainstorms and floods in different countries and regions, shared lessons learned therefrom, and offered new ideas on the control of flash floods from a global perspective. They are Prof. Daisuke Nohara from the Sustainable Society Laboratory at Kajima Technical Research Institute in Japan; Mrs. Zhang Xiaolei, IWHR Senior Engineer; and Prof. Frank Molkenthin from Brandenburg University of Technology Cottbus-Senftenberg, Germany. On August 27, 2020, the ICFM Secretariat held a webinar focusing on the Flood Challenge to Resilience. It brought together experts on water resources and disaster management, including Mr. Toshio Koike, Director of the International Center for Water Hazard and Risk Management (ICHARM).





Toshio Koike

Professor,
International Centre for Water Hazard and Risk Management,
Tsukuba, Japan

2020 Kyushu (Japan) Floods

Prof. Koike first introduced the sources of flooding affected Kyushu in July, 2020. Focusing on the reasons of flood triggering factors, he compared the 2020 Kyushu floods, the 2018 Western Japan floods, and the 1985 typhoon floods. A trend was revealed that large water vapor from the South China Sea and the Pacific Ocean has gradually concentrated in Japan, which directly led to frequent heavy rainfall. Weather maps, satellite images, and rainfall radar maps at 9:00 am on July 3 and 4 showed that local rainstorms formed by linear rain bands hit central Kyushu Island, causing Kuma River Basin become the most serious flood damage areas. The Kuma River Basin with an area of 1880 km^2, flows from its mountainous areas to plain areas through a long and narrow valley. Fierce floods from mountainous areas in the upper reaches triggered by heavy rainfall could not be discharged quickly and smoothly to plain areas due to backwaters in the long narrow valley. As a result, the basin between the mountain to the valley was most severely affected. Historically several severe floods had happened in this area. The peak flow was 5,700 m^3/s in the July 1965 flood and 5,500 m^3/s in July 1982. The 24-hour rainfall during the July 1965 flood was 161.9mm, but that of the 2020 floods was more than doubled to reach 410mm. The flood peak in 1965 was 5.05m, but hit 7.25m in 2021, higher than the historical average maximum level of the last five decades. In view of this, Prof. Koike concluded that "Kyushu faces a very severe flood situation in 2020".

Floods caused by heavy rainfall brought huge losses to Kyushu. The maximum inundation and depth on the embankments of the Kuma River was nearly 10m according to GIS mapping by using the images obtained by helicopters and SNS. Damage in Kumamoto Prefecture was huge, including 67 people missing or killed, 630 houses destroyed, 5,746 houses inundated, 2 dike locations breached, and 13 bridges lost.

As a result, a Guideline for the Creation of Countermeasures Against Flood Disasters during a Pandemic Situation (COVID-19) was developed by Japanese public health and disaster relief agencies and flood management research groups at the beginning of 2020. It helps individuals, communities, and local governments to cope with floods and typhoons by providing them with approaches to evacuation planning and shelter administration. In addition, the Collection of Critical Situations during Flood Emergency Response was compiled in the coronavirus context by the Public Works Research Institute and the International Center for Water Hazard and Risk Management. This report covers critical situations where local governments are confused or in dilemma during an emergency response under the dual crisis of flooding and coronavirus. It consists of eight chapters: initial response, headquarters management, structure in government office, collecting information, collaborating with stakeholders, issuing evacuation advisory, disseminating information, and shelters. For example, in the critical situation that "a temporary evacuees tested positive for COVID-19, but the high-risk contacts of the infected person are not known", the local government can take the following measures with reference to the report: 1) Prepare a reception sheet for listing names of evacuees; 2) Distinguish people suspected of being infected at receptions of designated evacuation sites/shelters. Any of them needs to make a self-declaration about his/her state of health. Space division should be implemented to quickly trace the close contacts; 3) Stock up on clinical thermometers to monitor evacuees' health state which may change if evacuation becomes prolonged; and 4) Make evacuees aware of the need to record and report their health changes, such as a body temperature rise.

Japan has experienced many floods since 2013. The country has summed up lessons learned from frequent floods and gradually improved flood management measures. In May 2015, the Flood Risk Management Act was amended, suggesting probable maximum rainfall for life saving. Later, *Policy Vision: Rebuilding Flood-Conscious Societies: Class A Rivers* and *Policy Vision: Rebuilding Flood-Conscious Societies: Class B Rivers* were successively launched, which have played a positive role in raising public awareness of flood control, protecting disabled groups, and promoting economic development. In May 2017, the Flood Risk Management Act was further amended, the Mega-Flood Management Committee was set up, and evacuation planning and drilling for handicap-accessible facilities were carried out.

Finally, Prof. Koike proposed to strengthen water-related disaster resilience and enable sustainable development through inclusive ways of "rebuilding flood-conscious societies", " the designed flood by coupling with climate models", and "basin-wide flood management". In terms of the designed flood, the Ministry of Land, Infrastructure, Transport and Tourism revised the Flood Management Plan by combining with the downscaling climate model and issued new process lines for designed flood of infrastructure. As for basin-wide flood management, river administrators should work together with all stakeholders including businesses and households to retain and retard storm water. In floodplains, measures of localizing inundation areas by setting and making full use of embankment structure and residential promotion to low-risk areas should be implemented to reduce economic losses. Non-structural measures are also necessary. For example, disaster preparedness and emergency evacuation based on early warning to reduce the economic and social impact; by mobilizing public support, local governments can quickly prepare for disasters and evacuate; and climate impact assessments will make post-disaster reconstruction easier; community-based evacuation will bolster mutual support and self-rescue. In one word, strengthening stakeholder collaboration and community resilience are crucial to surviving floods.

Daisuke Nohara

Ph.D, Senior Researcher, Sustainable Society Laboratory, Kajima Technical Research Institute, Japan

Flood and Mudflow Disasters Due to Heavy Rain Induced by Frontal System in Japan in Summer 2021

Mr. Nohara analyzed the extreme floods and mudflows in Japan in the summer of 2021 and shared relevant prevention and control plans. A summary was presented first: active frontal system associated with meandering westerlies caused prolonged heavy rainfall (non-seasonal for floods in summer) and resulted in flood and sediment disasters across the western and central Japan; the frequency of such non-seasonal weather was related to climate change; impacts of floods were mitigated in river basins where flood protection measures had been implemented; and there is still room for efforts like zoning in dealing with extreme floods, and terrain monitoring of high-risk areas would be one of the effective measures.

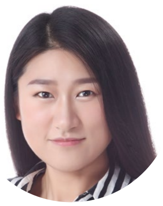
The three flood and mudflow disasters that hit Japan in summer of 2021 included the Atami mudflow on July 3, floods in the Sendai River Basin on July 10, and floods in six river basins from August 13 through 16. These disasters happened after the frontal rain system stayed over Japan for a prolonged period and appeared with a high-pressure system over the Sea of Okhotsk (which is typical at the end of the rainy season from June to mid-July). The slow-moving, almost stationary systems caused extreme weather events.

On July 3, 2021, a mudflow hit Izusan, Atami. The disaster that started from the Aizome River brought serious consequences. As of August 31, 26 people were killed and one was missing; 131 houses were fully or partially destroyed; roads were closed for 26 days; water supply was suspended for 1,100 households; and 165 local residents were stranded in shelters. The mudflow has the following two physical characteristics. It occurred at least ten times and flowed down for about 2,000m through the narrow valley from the origin located at 390m above sea level flowing to the sea (with a slope of 20% or 11°). Water content was estimated to be 31–36% and velocity to be 8–11 m/s as rainfall of 20–30 mm/h was observed during the mudflow, in addition to total rainfall of 500 mm four days before. The total volume of soil collapsed was 55,500 m^3. The mudflow of such a magnitude was a result of three main factors: illegal disposal of waste soil, area prone to debris flow, and prolonged heavy rainfall, as well as delayed decision making for evacuation. For example, for residential purpose large-scale filling was conducted in 2011, exacerbating land exposure and soil erosion and making the valley prone to debris flow. Given the maximum precipitation of only 25–30 mm/h during the prolonged rainfall, the local government issued the evacuation order as Level 5 Alert 35 minutes after the outbreak of the mudslide, which aggravated the impact of the mudflow. Recommended structural and non-structural measures include risk-zoning, building check dams, slope monitoring, and leveraging data support for response decision-making.

On July 10, a flood occurred in the Sendai River Basin after seasonal plum rains frontal system and a relatively static convection system formed in the middle reaches invoked heavy rainfall that far exceeded the design capacity of local flood control facilities. No inundation from the major rivers was observed in this event thanks to flood mitigation measures implemented after the 2016 catastrophic flood, such as dredging rivers and building flood channels upstream and downstream. Flood control capacity of the Tsuruda Reservoir was sufficient owing to dam upgrading. Short duration and spatial distribution of rainfall was also conducive to water storage. As a result, casualties of this flood were much lower than those of the same period in 2006. However, the situation would have been worse if rainfall concentrated in upper or lower basins.

Mr. Nohara also gave a brief analysis and summary of floods involving six river basins in Japan from August 13 to16 when prolonged heavy rainfall occurred across western and central areas due to non-seasonal stationary frontal system over the country. Inundation was smaller in the Rokkaku River Basin because of the implementation of flood mitigation works in the basin.

With regard to criteria for extreme weather events, Mr. Nohara conclued that in natural environments, the criteria should be based on the self-adaptability of specific environments, while in social environments such as cities, the criteria should depend on the disaster-bearing capability of human activities. Flood protection measures are needed when such criteria are exceeded. On the issue of minimizing casualties through early warning and resident evacuation, Mr. Nohara believed that warning issued during a quick disaster is too late; instead, an effective approach will be pre-disaster warning and evacuation. To this end, more effective real-time monitoring of early warning parameters for high-risk areas is necessary, so that early warning can be issued in a timely manner. Regarding the most important steps to prevent floods, he insisted that measures should go beyond past experiences and rest on current conditions while considering the impact of climate change. He suggested raising people's awareness of flood control and disaster prevention, in addition to stepping up structural measures.



Zhang Xiaolei

Senior Engineer, China Institute of Water Resources and Hydropower Research (IWHR), China

Prevention and Response to Extreme Rainstorms and Floods in China

Mrs. Zhang Xiaolei analyzed the rainfall process, flood magnitude, disaster losses, and disaster factors of urban floods and flash floods based on typical rainstorm and flood events of China in 2019 and 2020.

First, Mrs. Zhang introduced typical urban flood events in China. From June to July 2019, heavy rain lingered in southern China. From June 6 to 13, cumulative precipitation reached 100–250mm in Fujian, central and eastern Guangdong, and northern Guangxi each, and even as high as 832mm in Guilin City, Guangxi. On July 3–10, intensive rainfall exceeded 100 mm in the north of South China again, with noticeably 250–400 mm in northern Fujian. Such rainfall caused floods, hail, landslides, and mudslides in Fujian, Guangdong, and Guangxi. A total of 49 cities in eight provinces, including Zhejiang, Fujian, Jiangxi, Hunan, Guangdong, Guangxi, Chongqing, and Guizhou, were affected with direct economic losses of RMB 13.35 billion.

From June to July 2020, multiple rounds of heavy rainfall enveloped southern China, covering 15 provinces (autonomous regions and municipalities) including Yunnan, Sichuan, Hunan, and Hubei. Areas with precipitation higher than 100mm and 50mm reached 290,000 km^2 and 690,000 km^2 respectively. Rainfall surpassed 200mm in central and southern Anhui, eastern Hubei, and southern Jiangsu. Maximum daily rainfall hit 325mm/d in Qiting Town, Huanggang City, Hubei. Downpours triggered serious flooding in many places. Disasters affected a total of 24 provinces (autonomous regions and municipalities) including Jiangxi, Anhui, Hubei, Hunan, Chongqing, and Guizhou, resulting in direct economic losses of RMB 64.39 billion.

These two typical cases imply that urban areas suffer greater economic losses from flood disasters than rural areas as China's urbanization rate sets record high, climbing from 11.2% to 55.0% since the 1950s.

Urban floods vary among regions due to geographical factors. In coastal cities, floods are usually caused by storms, typhoons, and tropical cyclones. In southern cities, they are generally linked to river overflow or partial dam failure. In some northern inland cities, floods often inundate urban inland.

Then, four typical flash floods in China in recent years were showed. On June 12, 2020, a severe flash flood occurred in Zunyi City, Guizhou Province, with maximum hourly rainfall of 163.3mm/h in Bifeng Town, Zheng'an County, denoting a return period of over 500 years. The disaster caused RMB 93.8 million in direct economic losses while destroying 819 hectares of crops. 14 days later, a flash flood hit northern Mianning County, Sichuan Province, with a 50-year return period as maximum hourly rainfall registered 74mm/h in Yihai Town. A total of 1,661 hectares of crops were damaged, and some levees, communication cables, power lines, and bridges were battered, direct economic losses estimated to be RMB 740 million. During the flash flood in Luonan County, Shaanxi Province on August 6, maximum rainfall reached 127.2mm in 3 hours and 184mm in 6 hours, suggesting a return period of over 500 years. Direct economic losses amounted to RMB 1.93 billion, and 2,738 hectares of crops were damaged. During the flash flood in Guangxi on June 17, 2019, the maximum 6-hours rainfall even set a record high for 1,000 years.

"China's flash floods are sudden, destructive and unpredictable," said Mrs. Zhang. In view of these characteristics, China has established a community-based prevention and response system, which encompasses a responsibility system, simple monitoring and early warning facilities, publicity, training, and drills. The responsibility system is divided into five levels: national, provincial, county, town, and village. Take county-level responsibility system as an example. The county government is responsible for guiding communities at town and village in monitoring rainfall and water stage, and issuing warnings via county-level platforms. Each village is required to "establish a responsibility system, prepare a prevention plan, install a simple rain gauge alert, configure a set of early warning devices, organize training once a year, carry out drills once a year, create a temporary shelter for each risk zone, erect a publicity board, post a raft of warning signs, and distribute the knowledge card to each household". Standards are formulated by villages (communities) and sample materials are distributed in large scale. These efforts ensure the quantity and quality of mass monitoring and protection system by providing the basis and model.

After years of flash flood prevention and control, publicity media have gradually become diversified, such as short video apps, books, and films. Non-structural measures deployed in China help reduce casualties by 67% over past nearly 20 years, providing a "safe refuge for life" and benefiting all people. As urbanization advances rapidly, rainstorms and floods will cause larger losses in urban areas. The community-based prevention and response system that has been proved effective in both mountainous and urban areas should be extended on a large scale. As the priority will be addressing Black Swan events triggered by floods in excess of standards, it is necessary to fully mobilize grassroots and continue to strengthen the system for better response to various extreme flood events.

As for how to minimize casualties through early warning and resident evacuation, Mrs. Zhang believed that the key lies in monitoring, early warning, and community-based grassroots responsibility system. The emergency response capacity of disaster-affected areas can be effectively improved by monitoring rainfall in key areas and water level of key river sections and publishing warnings via county-level monitoring and early warning platforms. Regular publicity and education of local residents is an important measure to effectively deal with extreme disasters. Regarding the most important steps to prevent floods, Mrs. Zhang highlighted flood prediction technology and disaster risk identification and management. It is crucial to develop forecasting and early warning technology and make use of meteorological data and radar. Education and drills should be emphasized as well to raise residents' awareness of disasters and enhance in-depth risk identification and management. One of the important tasks for better prevetion from flash floods is to inform the younger generation of high-risk areas and emergency actions to survive a flood.

Frank Molkenthin

Professor,
Brandenburgische
Technische
Universität Cottbus-
Senftenberg,
Germany

Analysis of Flash Floods in Germany in 2021

Prof. Frank Molkenthin of Brandenburg University of Technology Cottbus-Senftenberg gave a detailed introduction to three flash floods in Germany during the 2021 summer, and put forward suggestions for dealing with extreme floods in the future through case studies.

First, the similarities and differences of these summer flash floods were listed. These events were all triggered by large-area low-pressure air currents moving toward central Europe, such as storms Xero and Bernd. Then, short-term intensive rainfall produced a large amount of surface runoff due to low infiltration capacity. In some places, rainwater accumulation led to flash floods as topography varies among regions. Prof. Molkenthin compared the three flash floods in terms of duration, affected range, disaster pattern, and casualties/economic losses based on specific data. The largest one hit the Eifel with rainfall lasting for nearly 14 hours, causing 181 deaths in addition to 10 billion euros in economic losses.

Later, Prof. Molkenthin reviewed the three flash floods. One of them hit Landshut, located in the River Isar valley which is 5 km wide and 400–500 m above sea level. The local government built a flood channel years ago in order to protect old urban areas along the river from flooding and it worked for years. However, on June 29, 2021, Storm Xero moving northeastward from France to Germany brought short-term intensive rainfall with a return period of 100 years to the urban area. The precipitation in Landshut downtown reached 58 mm within one hour, triggering an urban flash flood. But the critical factor is not the intensity of rainfall but the local impermeability and urban structures. For example, soil sealed by impervious pavements and urban infrastructure hindered rainwater discharge. In addition, drainage system renovation and green roof construction are compromised by a large number of historic buildings and structures in need of protection, which weakens flood control capacity of this time-honored city.

Another flash flood took place in Berchtesgaden, a village surrounded by mountains at an altitude of 600–2700 m. On July 21, the low-pressure system Bernd rotated from northeast to southwest. As clouds were partially blocked by mountain chains due to the terrain of Berchtesgaden, summer thunderstorms stroke mountainous areas with lower evening temperatures, carrying rainfall of 65 mm in four hours. Long-duration downpours generated intensive surface runoff and made creeks overflowed. At the same time, torrents on steep slopes caused mudslides and landslides, destroying houses and facilities within the village. In summary, the typical flash flood in Berchtesgaden was related to soil sealing caused by earlier lighter rain and local geological environment. As the underlying surface did not have sufficient capacity to absorb the subsequent heavy rain, surface runoff soared. Rainfall's concentration in mountain cirques with high slopes was critical to the flash flood. While flood protection in Berchtesgaden is difficult due to complex topographic structures, infrastructure construction in flood hazard areas also aggravated disaster damage over the last decades.

The devastating flood in the Eifel in western Germany on July 13–14 was the worst natural disaster met by Germany in 2021. Eifel is located in the mid-range mountainous range with deep and narrow valleys. It covers an area of about 5,000 km^2 at an altitude of 100–500 m. As Bernd remained for days in the region, the 24-hour rainfall in some areas broke the 70-year record, reaching about 153.5 mm. Historical comparison of peak discharge of Eifel-Ahr River indicated that this flood was at a similar magnitude to the 1910 flood. In Erftstadt, infrastructure including drainage and power systems suffered considerable damage and post-disaster reconstruction was particularly difficult. Following the upstream flood, the water stage in the Steinbachtalsperre Dam kept rising because the spillway was blocked by a large amount of debris from destroyed houses, trees, and various floating objects. Piping was also found in many places of the dam, posing a threat to 15,000 residents. It took the local government five days to stabilize the situation.

The similarities of the three flash floods in Germany could be summarized as: i) Heavy rainfall is the trigger for these floods, but the disasters were a combined result of rainfall intensity, temporal and spatial distribution, and topographical conditions in different regions; and ii) Climate change and human activities have certain impact on the frequency and damage of flood events. He suggested improving forecast accuracy in a targeted manner and establishing flood drainage and storage areas, reservoirs and other structures to minimize disaster losses. Policymakers and the media were advised to raise people's flood vigilance and environmental awareness to better respond to potential extreme flood events.

In open discussions, with regard to criteria for extreme weather events, Prof. Molkenthin indicated that the threshold for extreme flood events should be rainfall with an intensity of 50–60 mm/h, but the criteria be based on elements, such as urban and mountainous terrains and rainfall duration. As or Germany, an hourly rainfall of 50–70 mm is the standard for extreme flood events. On heavy casualties caused by the 100-year summer flood in Germany, Prof. Molkenthin commented that there were two reasons. On one hand, the government's early warning system is too complicated. In principle, the European Union issues the early warning first, and Germany issues the weather warning and transmits it to the state level and further to the county level. However, the theoretically effective level-by-level workflow slows down information dissemination, resulting in a delay in the issuance of early warnings. On the other hand, most local residents considered staying in their houses the safest way in face of floods. However, when the first wave of floods receded and the second wave peak arrived, local residents were trapped in their houses and could not be evacuated timely. The root of such misbelief is that the local area has never been hit by a disaster of the magnitude of this flood in history. As a result, they failed to fully understand the flood magnitude and adopted the wrong way of response, ending up with huge casualties and losses. Regarding the most important steps to prevent floods, Prof. Molkenthin highlighted the necessity to raise local residents' risk awareness and strengthen risk management while calling for attention to infrastructure construction in risky areas.

Philippe Gourbesville

Professor, Université Côte d'Azur (UCA); Vice President, Asia Water Council (AWC)

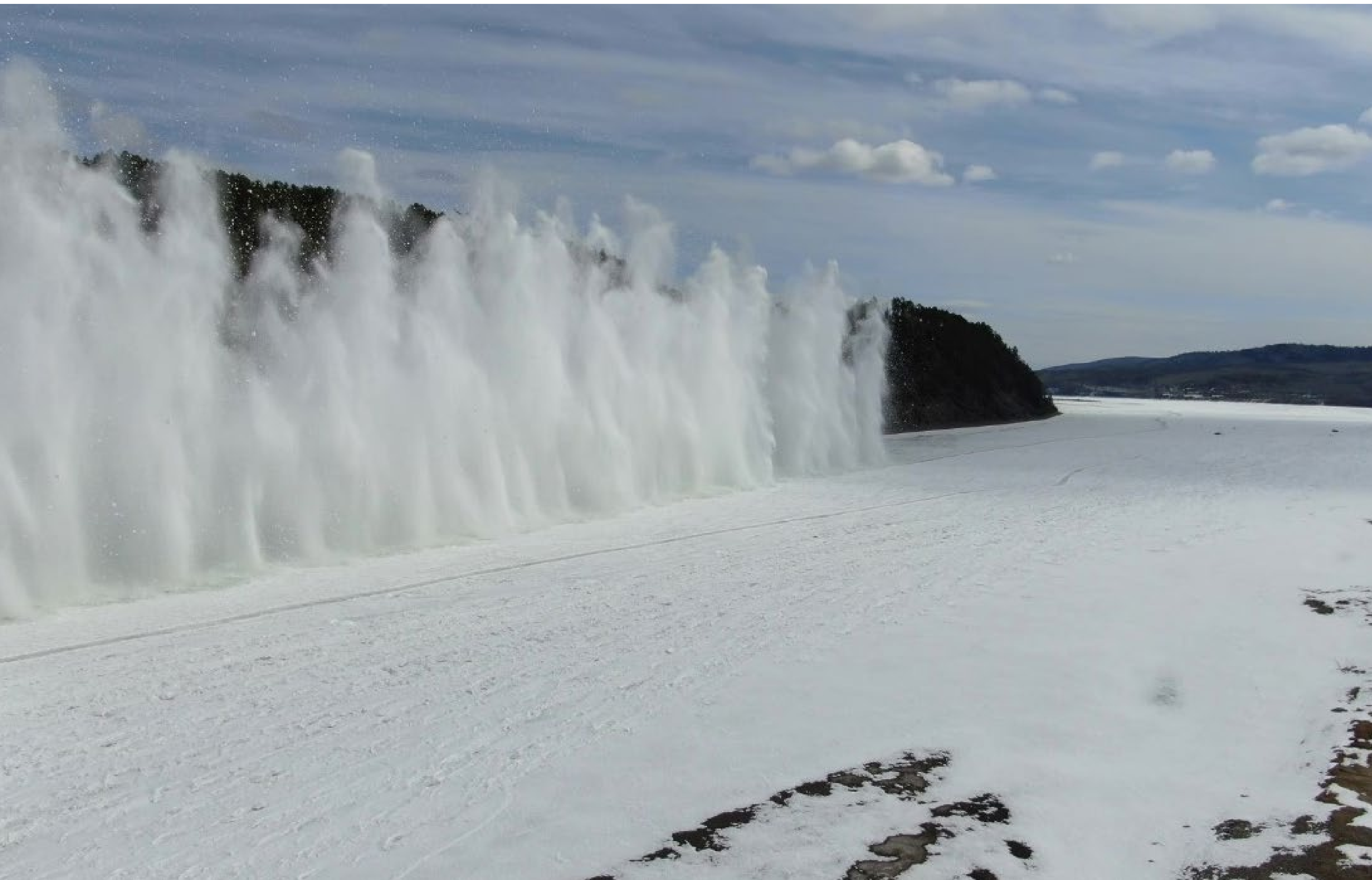
Flash Floods: New Challenges Brought by Global Extreme Rainfall

Prof. Gourbesville said that since its inception, FFP has been putting its focus on global extreme rainstorms and floods and explored and shared new technologies and methods on preventing and controlling flash floods. In the past hydrological year, floods frequently occurred worldwide, posing new challenges to the globe. Thus, this webinar was held to exchange experiences and lessons learned from-flood events that happened in Japan, China, and Germany from 2020 to 2021.

Storm Alex hit the Mediterranean coast of France in October 2020. The short-term storm (less than 24 hours) was very intensive, bringing over 500mm of cumulative rainfall in eight hours to an area of 750 km^2. Heavy rainfall caused a substantial increase in river levels and secondary disasters such as flash floods and mudslides ensued, resulting in 9 deaths and direct economic losses of more than 1.5 billion Euros. A major cause of the disaster was the cold air cyclone over the whole country. The cold air converged with the hot air caused by the high temperature of the Mediterranean coast of southern France, leading to torrential rains in some mountainous areas. Daily rainfall at some observatories even broke national historical records. Early warnings had been issued ahead by French authorities who accurately predicted the disaster-prone locations based on the existing modeling system though, the predicted rainfall (about 300 mm) was much less than the actual amount. That made the local residents fail to be aware of the severity of the disasters. When the massive flood carrying a large amount of sediment poured down the hillside, water works and structures along the river were destroyed, along with heavy casualties and losses. What's worse, the rescue was hampered by damages of transportation and communication facilities. Prof. Gourbesville denoted that, the existing forecast and early warning system need to be improved in terms of predicting floods exceeding the designed level. Therefore, in response to extreme floods, the local government should improve monitoring and early warning technology and strengthen the education and training of local residents in disaster preparedness, response, and recovery.

Managing Risks from Ice-jam Floods

On February 5, 2021, the ICFM Secretariat organized a webinar titled "Managing Risks from Ice-jam Floods" and invited 4 renowned experts specializing in water resources and river ice management to join the discussion. The panelists include ICFM Chairperson Prof. Slobodan P. Simonovic from Western University, Canada; Mr. Tomasz Kolerski, Vice Chair of the IAHR Committee on Ice Research and Engineering, and Associate Professor of Gdansk University of Technology, Poland; Mr. Guo Xinlei, member of the IAHR Committee on Ice Research and Engineering, and senior engineer of IWHR; and Karl-Erich Lindenschmidt, associate professor of University of Saskatchewan, Canada.



Slobodan P. Simonovic

ICFM Chairperson, Water Resources Specialist, Institute for Catastrophic Loss Reduction, Western University, Canada

Managing Risks from Ice-jam Floods

Prof. Simonovic introduced the ice dam incident on the Athabasca River in Canada in April 2020. With spring ice thawing in the upper stream of the river, the ice blocks built jammed and formed an ice dam about 25km in the river. Water level rose sharply, causing flooding in many parts of Fort McMurray in Alberta—a nearby city of about 70,000 people, and more than 13,000 residents evacuated. Data from the the Insurance Bureau of Canada indicated that economic losses caused by this event reached 230 million U.S. dollars. Therefore, as a kind of seasonal flood that seriously threatens people's lives and property, ice-jam floods must be given enough attention and scientifically managed.

Prof. Simonovic pointed out that we should manage to develop a trade-off between the flood damage and ice-jam management costs, and also understand the characteristics of ice-jam floods by distinguishing the floodplains of fluvial floods and that of ice-jam floods and taking into consideration of both of the risks.

Tomasz Kolerski

River ice engineering specialist, Vice Chair of IAHR Committee on Ice Research and Engineering, Poland

Ice-jam Flood Mitigation Methods

Mr. Tomasz Kolerski firstly presented the engineering and environmental problems associated with ice jams. Ice forming and jamming can affect many aspects related to hydraulic engineering, hydrology, civil engineering, ship design, ecology, etc. Specifically, the examples include ice jam and flood protection, ice damage on shoreline and onshore facilities, ice load on bridge and bridge piers, sediment transportation, design of icebreakers and arctic ships, and habitat improvement and river restoration in cold regions, etc.

Mr. Kolerski then introduced the processes of river ice formation and breakup and two scenarios of ice jam formation. In some areas, especially high-latitude regions, rivers normally ice up or freeze during winter when the temperature drops below 0°C. There are two preconditions of river ice formation: 1) When water is relatively calm, ice crystals form on the river surface and aggregate to become loose and fragile skim ice. Such an initial state of river ice is usually observed in areas with higher winter temperatures. Border ice is likely to emerge along riverbanks due to the low flow rate. If the temperature stays below 0°C, border ice will become thicker and expand toward the center of the river, freezing to be static cover. This phenomenon is often observed in reservoirs or lakes as well; 2) When water flows rapidly, ice formation could happen either on the rive surface or in the entire water body due to strong turbulence. Super-cooled water always forms into frazil ice, which may float in the water to become suspended frazil, or stick at the bottom of the river to become anchor ice, or produce pancake ice floating up to the river surface. When encountering ice cover, sharp bends or other obstacles, pancake ice piles up and connects with each other, forming juxtaposed ice cover or resulting in an ice jam. There are also two scenarios of river ice breakup in spring: 1) When water flow is steady, the force of water flow is not strong. Ice cover naturally experiences a thermal melt out, so ice jams or ice dams rarely occur; 2) When water flow changes rapidly, ice cover that has not fully melted would break up under the force of both water and wind, causing ice jams or ice dams. This might lead to ice-jam floods that affect normal boat navigation and facilitate shoreline erosion.

To tackle flood risks brought by ice jams or ice dams, Mr. Kolerski shared non-structural and structural methods for ice jam control. Non-structural methods are mainly artificial breakup ways, including: 1) ice blasting, a measure that has long been used in many countries and regions. It aims to remove the ice jams through ice cover blasting prior to the breakup period in spring and explosive blasting in the middle and late stages of ice jam formation; 2) mechanical ice removal. Commonly used equipment includes barge-mounted excavators, and amphibious ice breakers. An amphibious excavator (Amphibex) developed by Canada is able to pull itself to the ice layer through a backhoe and its weight to crash the ice; and 3) ice breakers, which have a faster speed and longer operating distance, yet require sufficient water depth to float. Structural methods are usually carried out by estimating the location and length of ice jams in advance, and installing ice control structures and facilities to limit the scope of ice jams. Mr. Kolerski mentioned the pier-type ice control structures being used in the Grasse River in New York of the United States. Ice booms are one of the most widely used ice control structures. They can float on water surface and effectively block the movement of ice floes. The effect of ice booms mainly depends on three factors: the Froude (Fr) number (which is the similar criterion number that must be considered for measurement of free-surface liquid flow, such as motion of ship on the water surface and flow in open channels) of ice cover, erosion velocity of ice control projects, and critical ice load.

Guo Xinlei

Hydraulic Specialist, Member of IAHR Committee on Ice Research and Engineering, China Institute of Water Resources and Hydropower Research (IWHR), China

Progress and Tend in the Study of River Ice Hydraulics

Prof. Guo Xinlei first introduced the background and demand for research on river ice hydraulics. More than 60% of high-latitude rivers around the world experience ice formation process in winter, ice jams and ice dams are frequent in rivers, canals, and reservoirs in cold northern regions and likely to cause floods. In addition, ice formation gravely threatens the safe operation of large water transfer projects. River safety and disaster mitigation during icing periods are major issues faced by departments in charge of flood control and drought relief. In this respect, summarizing the existing research results of river ice hydraulics and the difficulties in the current research and application may offer insight for better solutions.

Prof. Guo then reviewed the research progress in river ice hydraulics. Over the last five decades, the theories of river ice hydraulics across the globe mainly focus on 7 aspects based on timeline of "heat loss, ice formation, freeze-up, break-up, and influence". These 7 aspects contain hydrothermal mechanisms, formation and transportation mechanisms of ice runs, anchor ice and border ice formation and release, freeze-up ice jam mechanisms, break-up ice jam mechanisms, icing and blocking mechanisms on hydraulic structures, and flow-ice-sediment coupled mechanisms. As compared to China, research in other countries started early and has yielded rich results in the first 4 aspects. In light of these results, research in China, driven by practical needs, has focused on the basic theories and key difficulties in the other 3 aspects. In terms of ice condition forecast, Prof. Guo presented some of the commonly used numerical models, including one-dimensional mathematical model, quasi-two-dimensional mathematical model, two-dimensional mathematical model for ice process simulation, and hydrological forecast model. As to ice dam forecast, the focal point is mainly the forecast of ice condition before breakup and ice dam formation, and flood forecast after ice dam formation. Since the judgment and forecast of ice dam is made based on empirical formulas or specific indicators, new forecast methods are much needed after further probing into the structure evolution mechanism of ice dams. In terms of ice condition observation and mitigation, Prof. Guo expounded on the current technology and equipment system. There are more than 20 types of observation & mitigation equipment and dozens of observation parameters, including ice thickness, water depth, frazil concentration, water temperature, icing area percentage, ice run velocity, ice temperature, and ice pressure. Available ice breaking equipment normally include conventional icebreaking vessels, excavators, and blasting, etc. Also Prof. Guo shared the recent work conducted by IWHR innovation team of river ice hydraulics in monitoring, simulation, and regulation. The research work addresses several most concerned issues in the control of ice jams and ice dams, including the cause, location, time, and countermeasures.

Finally, Prof. Guo talked on the prospect of future research trend on river ice hydraulics. The first trend is the development of the basic theories of river ice hydraulics. Overarched by the existing framework, the heat source confluence of river bed heat flux and groundwater replenishment could be taken into account. Further research shall be conducted on the growth, flocculation, movement, and distribution of frazil ice, and the change in water flow and water level caused by anchor ice growth and release, as well as the water-ice and water-sediment nexus study, in a bid to enrich and expand the research scope of river ice hydraulics. The second trend is the forecast of ice conditions and tendency under changing circumstances. By considering the characteristics of meteorological and hydrological evolution in the climate change cycle, and the changes of northern rivers, research could be conducted to reveal the multi-year evolution of ice conditions in the middle and upper Yellow River under changing circumstances. On this basis, methodology and technology for ice condition forecast would be proposed accordingly, especially accurate hydrological-hydrodynamic forecast models at different scales in the medium and long terms, and then adopted in future ice condition forecast in changing circumstances. In addition, it is necessary to step up the technology and equipment for process-wide monitoring, early warning, and collaborative control. Prof. Guo highlighted the need to study on the principles and new methods for consecutive monitoring of ice jams and ice dams at different scales, and develop key sensors that could be integrated into the multi-parameter three-dimensional monitoring equipment system. The technology and equipment for ice-jam flood monitoring and data acquisition would supply monitoring technique and data support for building an integrated platform coupling intelligent forecasting, early warning, and ice-related disasters control. With regard to research on glacial lakes and glaciers on the plateau, Prof. Guo pointed out that glacial lake outburst floods often cause huge damage to life, property and infrastructure at the downstream. Glacial lake outburst has a complex process affected by many factors, so it is necessary to strengthen the research on its mechanisms, factors, and forecast. Experiments could be made on the evolution mechanisms of glacial lake outburst in low temperature, especially physical mechanisms such as undercutting and collapse of moraine soils that are eroded by water. Such studies will provide theoretical support and decision-making reference for forecast and simulation of glacial lake disasters.

Karl-Erich Lindenschmidt

Ph.D., P.Eng.
Associate Professor,
River Ice Engineering
Specialist, University
of Saskatchewan,
Canada

Flood Hazard and Risk—Assessment, Mapping and Mitigation

Mr. Karl-Erich Lindenschmidt explained the typical process of river ice jam formation in Canada through an example from Winnipeg—crushed ice from upstream accumulated at the front edge of the complete ice layer downstream, blocking the water flow and producing an ice jam. Due to the continuous stack of crushed ice with rough surface, the ice jam became increasingly thicker with greater friction against the water body, resulting in higher upstream water level. It is worth noting that when other factors remain unchanged, any slight movement of the ice jam base towards downstream would cause upstream backwater and changes in the ice jam shape. Therefore, it is difficult to forecast ice jams and the random approach or the Monte-Carlo analysis is needed.

Mr. Lindenschmidt introduced a flood risk assessment method, which considers both the hazard of ice-jam flood and the vulnerability of affected areas. Hazard concerns the probability of occurrence and intensity of flooding in the affected areas when the upstream backwater level rises. Vulnerability concerns the exposure and susceptibility of property (such as infrastructure and buildings) in the flood-stricken areas. Susceptibility could be described as: backwater level rising to a certain height may lead to disaster with a certain intensity. Based on hazard and vulnerability, the expected damage and the recovery period could be estimated.

Through the ice jam event in the Athabasca River, Mr. Lindenschmidt evaluated, via simulations, the effects and potential risks of three major mitigation measures, including dredging, artificial breaking, and dike. Dredging is mainly used for collecting and discharging riverbed sediments. Artificial breaking refers to breaking up the ice cover by using using Amphibex amphibious excavators and artificial icebreakers. Dikes are normally built in densely populated residential areas that are vulnerable to flooding. The simulation results showed that dredging can deepen the river channel, expand the cross-sectional area, and reduce the upstream backwater level; while artificial breaking is rather effective to destroy the intact ice surface and thus avoid ice jam caused by accumulated broken ice from upstream; plus dikes can effectively protect residential areas from the risk.

Mr. Lindenschmidt discussed the application of the Monte-Carlo algorithm to ice jam analysis. This method can be used to make ice-jam flood probability maps and calculate the average flood depth and total risk for each mitigation option. Combined with the vulnerability analysis of major property (structure types, damage curves, etc.), the algorithm could be used to estimate the annual expected damaging. His research team evaluated the effectiveness of various mitigation options, covering the average flood level after implementation of each mitigation option from the perspective of flood hazard, and the average annual damage from the perspective of flood risk. Both results demonstrated that dredging and artificial breaking are more effective.

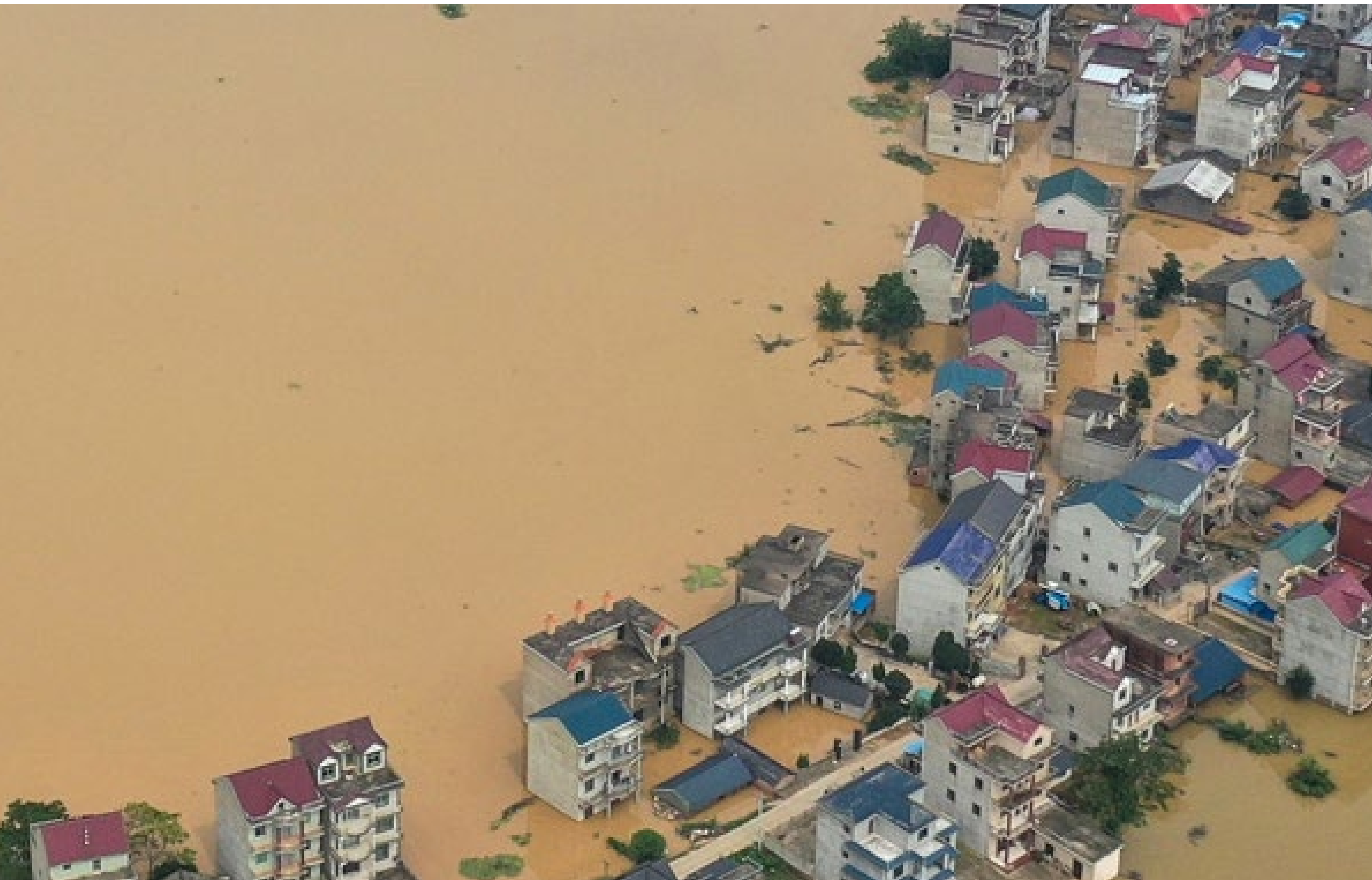
Regarding the timing of artificial breaking in Canada, Mr. Lindenschmidt stated that the best time is different among regions, depending on the specific time of river ice breakup each year. For long rivers in central Canada (such as the 25km-long Red River), artificial breaking starts earlier, usually about two months before the ice break-up (such as in February). For short rivers, artificial breaking starts later.

The novel method proposed by the research team for flood risk simulation and mapping is compared or incorporated with the conventional way for floodplain risk mapping based on flow conditions. It turned out that the simulation results are very sensitive to the resolution of digital elevation model (DEM), Mr. Lindenschmidt concluded based on an earlier sensitivity analysis of river ice parameters, boundary conditions, and DEM resolution. Hence, higher-resolution DEMs are required in future simulations to obtain the best results. For the next step, his team will conduct a simulation analysis of another mitigation option, i.e., affected areas zoning and infrastructure construction avoidance in high-risk areas, Mr. Lindenschmidt added.

At last, Mr. Lindenschmidt once again stressed that flood risk assessment should take into account both hazard and vulnerability, in addition to risk, so that appropriate mitigation options could be adopted.

2020-2021 Basin-wide Floods: Cases and Practices

This section compiles the presentations at the webinar on "The Flood Challenge to Resilience" and "Lowering Risk by Increasing Resilience" organized by ICFM Secretariat on August 27, 2020 and August 10, 2021 respectively. The panelists include ICFM Chairperson Prof. Slobodan P. Simonovic from Western University, Canada; Mr. Xia Jun, Academician of Chinese Academy of Sciences, and Professor of Wuhan University, China; Mrs. Molly Finster and Mrs. Carol Freeman, Resilience Specialist from Argonne National Laboratory, the United States; and Prof. Zhang Jianyun, China.



Slobodan P. Simonovic

ICFM Chairperson, Water Resources Specialist, Institute for Catastrophic Loss Reduction, Western University, Canada

Basin-wide Floods: Typical Events and Management Experience

Prof. Simonovic said in his talk, 2020 was a tough year for global flood control. Since August, almost every continent has been affected by floods to varying degrees. Flood control this year faces double pressure in the midst of the epidemic that has been impacting the economy and society.

2020's floods set new standards in frequency and severity. To lower the losses of affected people, work needs to be done from three aspects in face of a more complex crisis context. First, the government should strengthen risk and emergency management capability for adequate loss prevention. Second, physically resilient structures should be built and integrated with non-structural measures. Third, implementation of long-term and forward-looking planning for flood control as well as municipal administration is very necessary, such as flood maps and floodplain management. Fostering a culture of preparedness requires going beyond traditional programs by engaging all stakeholders at the federal, state, local, territorial, and private levels.

Prof. Simonovic applauded the sharing of firsthand experience from current events across the globe. A review of global flood control measures can help experts and decision-makers understand the situation and identify learning lessons from the flood events in 2020.

Prof. Simonovic affirmed the key role of reservoirs in flood management. However, most of the reservoirs for flood control were designed following the past standards. Since such standards, subject to new climate and flood situations, are constantly changing, it is critical to evaluate the existing reservoirs and their storage capacities.

Xia Jun

Professor,
Academician of
Chinese Academy of
Sciences, Director,
Research Institute
for Water Security,
Wuhan University,
Wuhan, China

2020's Major Floods in Southern China

Prof. Xia Jun provided an overview of the magnitude and consequences of the 2020 flood taht happened in the southern part of China. In 2020, many rivers and lakes in southern China such as the Yangtze River, Huaihe River, Poyang Lake, and Taihu Lake experienced major flooding. Referring to the data released by the State Council Information Office and the National Meteorological Administration of China, the 2020 rainy season (Meiyu period) in the middle and lower reaches of the Yangtze River lasted for 23 days, longer than usual, with an average rainfall of 753.9mm, which was 68% higher than the largest since 1961. Statistics as of August 13, 2020 showed that 634 rivers across the country were threatened by flooding exceeding the warning water level, causing direct economic losses of 178.96 billion RMB (15.5% more than the past five years' average). 63.46 million people (12.7% more than the average of the past five years) in total were affected, with 219 dead and missing (54.8% less than the past five years average), and 54,000 properties were destroyed (65.3% less than the past five years average).

On the management of extreme floods in the COVID-19 context, Prof. Xia pointed out that 2020 was a very difficult year for China and the world. At the critical moment when the pandemic soaring in Wuhan, the Chinese government and people worked together and quickly brought the epidemic under control within just two months through scientific decision-making from a national perspective, and implementation of effective quarantine and prevention measures. This prompt action mitigated the pressure from flooding with the arrival of flood season in May. Especially during the flood season in the Yangtze River Basin, the Chinese government planned ahead and made careful arrangements to ensure both the epidemic control and the flood preparedness were considered. In terms of epidemic control, effective measures including medical treatment, nucleic acid testing, mask-wearing, and health code have been implemented. In terms of flood preparedness, integrated measures of structure and non-structure were enforced. Despite the emerging challenges in the ever-changing environment, the Chinese people have learned from the past and gained valuable experience in flood control planning and the application of structural and non-structural measures.

Prof. Xia introduced the flood control engineering system in the Huaihe River Basin through a case study of China's response to the 2020 Huaihe River flood. The Huaihe River is deemed as the boundary between the north and the south of China and its Basin is prone to floods and droughts. It drains an area of about 270,000 km^2 with a population of nearly 165 million, the highest population density among China's major river basins. After years of governance in the Huaihe, a basin-wide flood control engineering system has formed, featuring "upstream retention, midstream storage, and downstream discharge". In July 2020, the meteorological and hydrological forecast showed that the Huaihe Basin was expected to suffer heavier rainstorms than in the same period of past years relevant flood control departments and local governments relocated in advance 20,000 people living in the Mengwa flood diversion area. And Wangjiaba Gate was opened to discharge floodwater to the Mengwa area. With coordinated action taken in the upstream, midstream, and downstream, flood control has achieved remarkable success and the residents' safety nearby the basin was ensured.

Prof. Xia went on to explain the flood control situation of the Yangtze River Basin in 2020. Three numbered floods (No.1, No.2, and No.3) formed successively in the Yangtze River Basin in 2020 after entry into the rainy season in May. Downpours are concentrated in the middle and lower reaches, with the Poyang Lake Basin seriously affected. On August 11–17 2020, another two numbered floods (No.4 and No.5) occurred resulted from heavy rainfall in the upper reaches of the Yangtze River. At that moment, nearly 10.09 million people in Wuhan Province received nucleic acid tests to consolidate the COVID-19 prevention. Meanwhile, to cope with severe flood conditions, professional rescue teams and army were sent to the front line for flood control and emergency rescue. These efforts, plus the key role played by the Three Gorges Project, have successfully responded to the largest inflow to the Three Gorges Reservoir since its establishment, manifesting a remarkable result eventually.

On lessons learned from the southern China floods in 2020, Prof. Xia noted that the 7 major river basins in China are located in the eastern monsoon region, and cover almost 95% of the national population. Both in the past and the future, they tend to face the impact and threat of floods. Hence, the social and economic development of the Yangtze River Basin denotes the Chinese nation's continual fight against, adaptation to, and management of floods. Prof. Xia concluded with three main points: 1) Flood is a natural phenomenon with high uncertainty. The temporal and spatial distribution of flooding are affected by climate and LUCC changes. A major issue of flood control and disaster mitigation in the new era is basin-wide flood control strategies under the changing environment, especially in a global changing climate. This requires applied and basic research and appropriate countermeasures to be conducted; 2) Floods have strong social attributes as they are closely linked to human survival and development. Structural measures are important, but inadequate, which is why they should be combined with non-structural measures (early warning and scheduling) as well as scientific flood management measures. For example, the proper use of flood diversion areas and the adaptive management of flood insurance could minimize the risks and losses of floods. The necessity of the integrated approach has been proved in the relocation of residents when the 2020 Huaihe River flood occurred, and 3) People should learn how to live with floods. As population is expanding in the floodplains, floodplain management and urban flood control particularly in southern China will face more challenges. The maximum peak flow of the 2020 flood in the Yangtze River Basin was below the record set by the 1998 flood, but the water level was abnormally high, fully demonstrating the outcomes brought by the changes in river banks and flood diversion area. It is necessary to reflect on the way to co-existence with floods, and the methods for river governance. In addition, since climatic zones and socio-economic backgrounds vary in different countries, management measures should be customized for better adaptation. Therefore, international cooperation is essential in sharing best practices and experience.

Zhang Jianyun

Academician of Chinese Academy of Engineering, China

Managing the 2020 Floods of the Yangtze River—Structural and Non-Structural Measures

Prof. Zhang Jianyun explained the vital role that the integrated engineering and non-engineering measures have played in managing the 2020 catastrophic floods in the Yangtze River Basin.

Prof. Zhang outlined the characteristics of floods in China and the evolution trend in a changing climate. According to the National Flood Defense Plan, about two-thirds of the area in China is exposed to the risk of flooding, and about 400 cities have already experienced a varied degrees of flooding. Data showed that the number of flood events in the 20th century increased by 122% compared with the 19th century, among which the coastal areas face a higher risk of flooding due to rising sea levels associated with global climate change. In recent years, climate change has become a focused issue in flood management. As the World Meteorological Organization report claimed, the global average temperature continued to rise in 2020 and reached 1.2°C higher than the 1850–1990 average. A warmer climate will bring more storm events and higher flood risks. While the sea level rise poses additional challenges, for example, sea level around China rose by 3.4mm per year between 1980 and 2019, which means a higher risk of flooding in coastal areas. Thus, the flood has been one of the most serious disasters in China; also such risk will increase in the future under the impact of global climate change, so flood management brooks no delay.

Prof. Zhang then described the background information of the Yangtze River before probing into the basin flood in 2020.With a length of about 6,300 kilometers, the Yangtze River is the Asian’s longest and the world’s 3rd longest river. It drains an area of about 1.8 million km^2, and the Yangtze Economic Belt serves as a powerhouse of Chinese economy by hosting over 40% national population and GDP, providing more than one-third of China's fresh water and food. However, featuring a typical monsoon climate, this area is exposed to a very high risk of flooding.

The 2020 Yangtze River floods mainly had the following prominent characteristics: 1) Heavy precipitation. From June to August 2020, rainfall in the Yangtze basin averaged 635 mm, 30% more than the multi-year average. Rainfall in the middle and lower reaches was even larger, which was more than twice the multi-year average. Specifically, rainfall in Anhui Province downstream from June to July set a record high of 856 mm, 2.1 times the average of many years. The extreme value observed in a gauge station was as high as 2,179 mm; 2) High flood flow. From July to August 2020, there were five flood peaks in total, contributing to the largest inflow of the Three Gorges Reservoir since its operation. The flood flow in the Poyang Lake Basin and the water level at the 150km downstream stretch near Nanjing also reached a record. Emergency actions were enforced in response to over 5,000 damaged spots of tributary dikes, and 892 flood diversion areas were put into use. In this sense, the 2020 flood is the severest basin-scale event since 1998. Despite higher severity than the past extremes, this flood caused fewer losses in both economic and life terms, with direct economic losses equivalent to around half of that in 1998, and casualties, one-tenth of that in 1998.

Prof. Zhang pointed out that the integration of engineering and non-engineering measures have played a vital role in the Yangtze River flood control. From the engineering perspective, the joint scheduling of cascade reservoirs was implemented in a refined manner. The engineering system for Yangtze River flood control is based on various reservoirs, dikes, and flood diversion areas. 41 upstream reservoirs with the Three Gorges Reservoir as the core were in a joint operation, providing a water storage capacity of 88.4 billion m^3 that protected over 30 cities and 100 million people. From the non-engineering perspective, the forecasting system was applied in collaboration with the decision-supporting system for flood management. For instance, the Xin'anjiang Model has been one of the most widely used forecasting models in China. Inputs to this model include precipitation, evaporation, and flow from upstream. Runoff concentration is calculated using the Unit Hydrology method or the Nash Linear Reservoirs method, and river flow routing is calculated by the Muskingum method. This forecasting system has been validated during the 2020 Yangtze River flood. By comparing the regressed inflow to the Three Gorges Reservoir (without considering the reservoir retention) with the measured inflow, the statistics indicated that the measured inflow was drastically reduced since 24.6 billion m^3 of flood water was retained by the upstream reservoirs. The above-mentioned 41 reservoirs together retained 50 billion m^3 of flood water. This helped, in the 5th flood peak, lower the water level from 46.8m to 43.2m, and the outlet flow of the Three Gorges Reservoir from 88,000m^3/s to 75,000m^3/s. Owing to the cascade reservoir retention, the water level at the Shashi station was kept below 45m (the warning level of the flood diversion areas) while substantially attenuating the flood peaks. The avoided use of the Jingjiang flood diversion area protected 600,000 people from flooding and 2.24 million km^2 of land. This significantly reduced economic losses, and safeguarded the downstream cities, such as Wuhan, the capital city of Hubei Province, on the middle reaches of the Yangtze River.

Prof. Zhang concluded that flood management of the Yangtze River Basin in 2020 has rendered huge economic and social benefits. First, timely and accurate forecasting well informed the decision-making on reservoir operation. Second, the engineering system comprised of the Three Gorges Reservoir and 40 upstream reservoirs was crucial to successful flood control. Third, the integration of engineering and non-engineering measures played an indispensable role in flood management.

Molly Finster

Decision and Infrastructure Sciences, Argonne National Laboratory, US Department of Energy, Argonne, Illinois, USA

Michigan Dam Failures: A Messaging & Evacuation Case Study I

Two resilience experts from the Argonne National Laboratory presented a case study of the Michigan dam failures incident in May 2020 in the United States,

Dr. Molly Finster first gave a brief introduction to the Michigan Dam Safety Project. The project is jointly funded by the Federal Emergency Management Agency's (FEMA) National Dam Safety Program and the National Integration Center. Its main objective is to observe damages from the recent Michigan dam incidents and understand what occurred; study and compare actual flood data relative to inundation model results; study the hydrologic and hydraulic characteristics of the post-dam failure floodplain; and gain insights from the rapid evacuation of communities at risk.

In the counties of Gladwin and Midland in Michigan, 6 reservoirs were all built between 1912 and 1925, originally for hydropower generation rather than flood control. Four dams on the Tittabawassee River, namely Secord, Smallwood, Edenville, and Sanford, are managed and operated by the same company. The other two dams (Chappel and Beaverton) are located on the Cedar and Tobacco River upstream and administered by the county and the city respectively.

On May 17 morning, 2020, a stalled low-pressure system and weather front developed in the southern part of the Great Lakes region and brought heavy rainfall to southeast Michigan. The rainfall continued to the afternoon of May 19 and reached 100–200 mm over 3 days.

Due to heavy rainfall, historic flooding already occurred in several rivers on May 18, the day before the dam failure. In particular, the Tittabawassee River in Midland County experienced the worst flood in its history. Therefore, on the same day, all dams in the region were running with gates wide open. It is noteworthy that the Chappel Dam on the Cedar River upstream had an overtopping near the generator house on one side, but was able to mitigate and prevent failure after the efforts made by dam operators and engineers.

At 0:30 am on May 19, dam operators became aware of the serious problem and worsening situation, thus initiating the emergency action plan process for all 4 dams on the Tittabawassee River to release a prompt warning message. At 3:30 am, Smallwood Dam sounded the siren because high water levels were concerning. From morning to afternoon, state government officials, safety office officials, and dam engineers were all working at the Edenville Dam site to address safety issues. Nevertheless, floodwater broke through the easternmost part of the Edenville Dam at 5:45 pm, causing the worst dam failure in Michigan's history, and continued to rush through the Sanford Dam at 8:00 pm. Although gates were already open, the water level at the Sanford Dam rose rapidly due to discharge from the Edenville Dam, finally leading to dam overtopping and outburst.

The Tittabawassee River crested at 10.68 m on May 20, the day after the rain stopped. Until May 22, inundation could still be observed on the satellite. This historic flood was the worst in the cities along the Tittabawassee River and caused grave damage to infrastructures such as buildings, roads, and bridges. Fortunately, nearly 11,000 local residents were evacuated safely with no loss of life.

Dr. Finster also mentioned the problem of aging infrastructure. For dam safety, owners and operators are both aware of the vulnerability of aging infrastructure and the associated risks. It is necessary to inform the surrounding communities about the risks, in addition to planning and repairing the aging infrastructure. A disaster prevention drill plan is also very important to strengthen the linkage among multiple departments for a quicker response to dam failures, Dr. Finster added that in the process of dam reconstruction, relevant measures should be considered to increase its resilience to floods.

Carol Freeman

Senior Emergency Preparedness and Resilience Analyst, Decision and Infrastructure Sciences, Argonne National Laboratory, US Department of Energy, Argonne, Illinois, USA

Michigan Dam Failures: A Messaging & Evacuation Case Study II

Dr. Freeman shared the experience of evacuation in terms of alerting process, warning diffusion, and individual behavior, highlighting the importance of multi-shareholder coordination, real-time update, disaster prevention drills, and evacuation plans.

In this case, the Argonne National Laboratory referred to *A Guide to Public Alerts and Early Warnings for Dam and Levee Emergencies* issued by the United States Army Corps of Engineers, which focuses on how the public receives the notification and takes prompt protective action.

In the Guide, the warning and protective action initiation timeline were proposed. Dr. Freeman analyzed the timeline in three main focuses: 1) time from threat detected to a warning issued; 2) time from a warning issued to a warning received, and 3) time from warning received to protective action initiated.

Dr. Freeman explained the whole process of successful evacuation in Midland County. One important factor in this process is the relationships between local governments and various departments concerned, including Gladwin County upstream, National Weather Service, Boyce Hydro, and Dow Chemicals. Numerous informal exchanges were conducted between key players via phone calls and text messages, in addition to formal notifications.

The NIXLE system was frequently used during this incidence in Midland County. This local alert and warning system, with which local dispatchers are very familiar, can be used for warnings of various emergencies including traffic accident. Many communities had purchased the NIXLE alert and warning service before the event. Although messages are not pre-scripted, brief and frequent updates containing the specific locations and clear instructions can be posted by the dispatchers. Each message conveyed the urgency of the situation, informing residents that the dam was about to fail. Opt-in sign-up for NIXLE is encouraged through simple registration via the 911 website or the county/city websites. Bilingual alerts in English and Spanish are available.

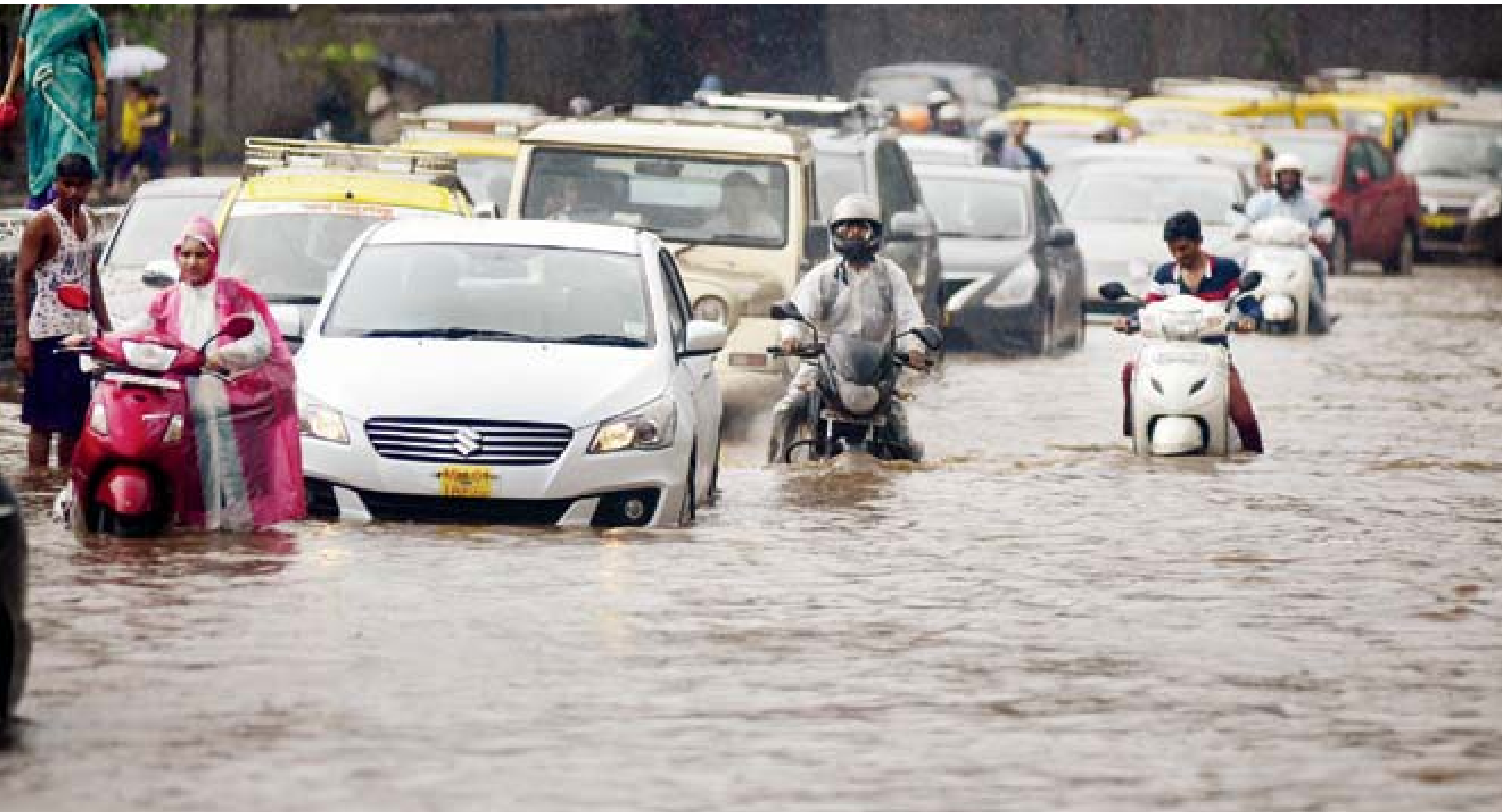
Meanwhile, the Wireless Emergency Alerts (WEA) system was used for the first time. The system is a very important part of the integrated public alert and warning system of the United States. Alert was geo-targeted to all mobile phones with a 90-character limit in the range of cell towers. This system is not subject to bandwidth limitations, and citizens do not need to sign up for this service. Since it was used for the first time in the event, Central Dispatch led the WEA message creation and dissemination.

Dr. Freeman stressed the importance of information consistency, and Midland County has done a good job in issuance. On May 16, 2020, Midland County 911 Dispatch barely posted any message on the Internet. Yet two days after, amid increasing concerns about dam safety caused by non-stop rainfall, Midland County 911 Dispatch began to issue alerts to communities, and then amplified the alerts through social media including Twitter and Facebook. On May 19, frequent updates were issued again, 27 alerts spread widely on Twitter and Facebook, and the number declined with the start of the evacuation. At the same time, the public started sharing NIXLE alerts on social media for those who didn't opt-in to the system, and proactively addressed questions with a "should I evacuate" map that helped indicate the distance from the flooded area.

The individual behavior in this incident helped nearly 11,000 people evacuate in advance, and this pre-event evacuation avoided a night-time evacuation on dark, flooded roads. This case also shows that local awareness of flood risk was heightened due to extensive flooding experienced in 2017, and community-wide concerns over aging infrastructure and dam maintenance and reliability were raised as well.

Real-time Urban Flood Forecasting: Current Status and Future Challenges

On June 14, 2021, ICFM Secretariat organized a webinar themed as "Real-time Urban Flood Forecasting: Current Status and Future Challenges", 4 experts were invited to have discussion on topic of real-time urban flood forecasting and its role in coping with challenges for different stakeholders. The panelists included ICFM Chairperson Prof. Slobodan P. Simonovic from Western University, Canada; Prof. Subhankar Karmakar from the Department of Environmental Science and Engineering, Indian Institute of Technology Bombay, India; Prof. Subimal Ghosh from the Department of Civil Engineering at the Indian Institute of Technology Bombay, and Convener of Interdisciplinary Program, India; Prof. Xu Zongxue, Distinguished Professor of the College of Water Sciences at Beijing Normal University, and Director of the Beijing Key Laboratory of Urban Hydrological Cycle and Sponge City Technology, China; and Mr. Roxy Mathew Koll, Scientist of the Center for Climate Change Research and the Center for Advanced Training in Earth System Sciences and Climate at the Indian Institute of Tropical Meteorology, India.



Slobodan P. Simonovic

ICFM Chairperson, Water Resources Specialist, Institute for Catastrophic Loss Reduction, Western University, Canada

Real-time Urban Flood Forecasting

Prof. Simonovic, made an opening introduction for the webinar. Around 55% of the world's population currently lives in cities, the proportion is still on the rise and expected to reach about 60% to 70% by 2050. Many metropolises located in coastal areas are vulnerable to various climate change factors and prone to floods. In order to reduce flood damage, a variety of structural and non-structural measures have been taken around the world, among which real-time urban flood forecasting as a non-structural measure is gaining more importance. Countries have realized that more sufficient and accurate data support is necessary to improve the precision of flood forecasting in response to the challenge of urban flooding.

Subimal Ghosh

Professor, Dept. of Civil Engg., Convener, Interdisciplinary Programme in Climate Studies, Indian Institute of Technology Bombay, Mumbai, India

Urban Meteorology and Flood Forecasting

Prof. Ghosh talked on the urban hydrometeorology and flood forecasting. He first introduced the Clausius Clapeyron Theory in meteorology: With per degree Celsius increase in temperature, the water vapor capacity of atmosphere increases by 7.5%. Such an increase is strongly reflected in extreme precipitation. The IPCC AR5 report stated that, regions with extreme events on a global scale are likely to increase, especially extreme precipitation comparing with regions extreme drought. Frequency of heavy precipitation events is likely to keep increasing, in particular in the high latitudes and tropical regions.

Prof. Ghosh shared the research findings of his team, including scaling results on temperature and precipitation over central and southern Asia. The results showed that in recent years, extreme rainfall has increased with evident spatial variability in India, noticeably in central India. Important land factors affects rainfall normally consist of urbanization, land use and coverage change, terrestrial water management, atmospheric aerosols and dust. Impacts of urbanization on rainfall are reflected in heat and moisture growth, urban heat island effect, more atmospheric aerosols, and changes in airflow and eddies. As to impacts of short-duration intensive rainfall on catchments of various scales, an analysis revealed that the impacts of daily rainfall extremes on small (≤1,000km^2) and large (>1,000km^2) catchments do not vary much, but the former is more affected with worse damaged than the latter by 3-hour extreme rainfall.

Prof. Ghosh also introduced three Weather Research and Forecasting (WRF) models for urban floods: 1) without urban canopy model (WRF-NoUCM); 2) Coupled with a single-layer urban canopy model (WRF-SUCM); and 3) Coupled with a multi-layer urban canopy model (WRF-MUCM). Among them, simulated precipitation by WRF-MUCM is relatively more close to the observed data.

Then, Prof. Ghosh expounded on India's first real-time urban flood forecasting system built for the city of Chennai. Data needed in the system cover historical rainfall, coastal conditions, hydrology conditions, and terrain conditions. By exploiting data processing, model simulation, and predictive analysis, a real-time flood forecast could be obtained and released to the public. The forecast accuracy is highly related to flood model, model calibration and validation, and data quality. In an effort to achieve flood forecasting at different time scales, the flood data should source from various cases of different time scales (ranging from several years to hundreds of years), storm duration (ranging from several hours to several days), tide conditions, and historical climate conditions.

India's real-time urban flood forecasting system involves different departments as the data sources. The Ministry of Science of India and the Coastal Center are responsible for flood forecasting and tide forecasting models, data for hydrological forecasting is collected by sensors deployed in various areas in the upper reaches of Chennai. Radar monitoring, public surveys and digital elevation models (DEM) updated every five years provide input for the data bank as well.

On the temperature-precipitation nexus on a short time scale, Prof. Ghosh shared two points of view: 1) On an-hour scale, temperature change before rainfall could be used as a harbinger of rainfall; temperature also changes after rainfall (due to rainfall, cloud cover, etc.) under normal circumstances, but such change may not support the judgment on the probability of extreme rainfall in the future; 2) When temperature is high (e.g. above 34°C), vapor often only lasts 3 to 4 hours, so hourly extreme rainfall may occur, but daily extreme rainfall will not be likely because it requires moisture.

Prof. Ghosh concluded that both global and local climate factors might affect extreme rainfall and flood patterns in the future, so the forecast and early warning system should consider multiple factors comprehensively.

Xu Zongxue

Distinguished Professor, College of Water Sciences, Beijing Normal University; Director, Beijing Key Laboratory of Urban Hydrological Cycle and Sponge City Technology, China

Real-time Scheduling and Forecasting System of Urban Flood in Coastal Areas

Prof. Xu first introduced the recent background of urban floods. He pointed that urbanization and climate change have greatly interfered the hydrological process. According to the 5th IPCC Assessment Report, global warming, extreme precipitation, and floods have become more frequent, and most of the global risks caused by climate change impact cities. In particular, China has been undergoing rapid urbanization over the last two decades, with urbanization rate rising from 30% in 2000 to 59.6% in 2018. Urban heat island effect and rain island effect have intensified as a result. A sequence of problems have also arisen from urbanization, such as more frequent floods, urban water shortage, and urban water environment destruction. Prof. Xu then reviewed the first major urban flooding caused by downpours in Beijing on July 21, 2012, and the 2020 urban flooding in Guangzhou where that part of the subway was inundated, and in Jingdezhen, Jiangxi Province and Bazhong, Sichuan Province.

Sponge cities represent an active attempt by the Chinese government to deal with urban floods. A sponge city refers to a city that has good elasticity in adapting to environmental changes and coping with natural disasters. When it rains, it absorbs, stores, seepages and purifies water, and when needed, "releases" and use the stored water. The construction of sponge cities should consider natural precipitation, surface water and groundwater systems, coordinate water supply, drainage and other links of water, and fully understand the complexity and longevity in the system. Typical facilities of sponge city include permeable pavements, rain gardens, green roofs, vegetative swale, bio-retention cells, infiltration trenches, etc.

As a crucial technical tool for sponge cities construction, urban flood modeling could be applied and customized as a real-time flood scheduling and forecasting system in a way to optimize urban flood management. Prof. Xu also introduced the research progress of his team on integrated model and forecasting system for urban floods, and current computational methods and application fields of hydrological and hydrodynamic models. Comparing with natural river basins hydrodynamic simulations, the hydrological and hydrodynamic simulations of urban floods are more complicated mainly because of the complex spatial distribution of urban impermeable and permeable area, and significant three-dimensional layered structure of drainage system, while also considering surface runoff, overland flow, pipeline flow, and stream flow. For example, the dynamic wave method is required to describe the confluence process of drainage pipelines, and the two-dimensional shallow water equation is used to analyze the evolution process of urban floods.

At the data layer, multi-source data integration should be adopted by collecting and analyzing information from satellite remote sensing, gauge observation, and radar, etc. Among them, remote sensing has been widely used in flood monitoring, flood area extraction, and remote sensing image interpretation. Nowadays, integrated model coupling hydrological, hydrodynamic and machine learning models have been applied to the real-time forecast of urban floods through simulating complex urban hydrological processes. Other related technologies for flood monitoring and forecasting contain deep learning, data mining, and parallel computing.

A case study in Fuzhou, a southern city in China, was taken as a reference. Due to the city's location, typhoons and heavy rains frequently visit every year from July to December, resulting in a major issue of flooding for the city. To strengthen urban flood control and water integrated management, the local government has initiated and developed a scheduling system of urban water networks and a digital platform for urban water affairs. Joint scheduling of urban water systems has thereby been enabled by relying on the "eye" (monitoring system using IoT, AI, AR, and VR technologies), the "brain" (data analysis system using big data, artificial intelligence, and cloud computing), and the "hand" (automated control system using information technology). The model development for this system generally underwent a few stages including data pre-processing, urban flood simulation, hydraulic structure scheduling, water quality simulation, and urban flood forecasting and early warning. Four main functions of this system in Fuzhou was highlighted as inquiry and monitoring of rainfall, typhoon, inundation, and water level; generation and optimization of scheduling schemes; real-time urban flood simulation and result analysis; and real-time scheduling system.

Prof. Xu concluded that an integrated, accurate, and efficient hydrological and hydrodynamic model is key to the real-time forecasting. Multidisciplinary collaboration helps address the problem of urban flooding. The complementary respective advantages of various disciplines should be employed to establish a data-model-forecast-command integrated intelligent management system, including hydrology, hydrodynamics, remote sensing, artificial intelligence and other fields.

Roxy Mathew Koll

Scientist, Centre for Climate Change Research, Indian Institute of Tropical Meteorology, Adjunct Faculty, University of Pune, IMD Meteorological Training Institute, and CAT-ESSC, IITM, India

Increasing Risks and Challenges of Compounding Floods in a Changing Climate

Mr. Roxy Mathew Koll delivered opinions on risks and challenges brought by compound floods to cities in a changing climate. Due to climate change, natural disasters no longer appear in a single form. Many cities around the world (especially coastal cities) have faced the impact caused by superposition of multiple extreme weather conditions such as heavy rainfall, tropical cyclones, storm surges, and sea level rise. The resulting compound floods have obviously exacerbated the risks and disaster losses.

About 30% of the global low-elevation coastal zone (LECZ) population, that is, 189 million people, lived in the 100-year floodplain in 2000. The number will increase to about 268–286 million by 2030. By 2060, up to 411 million people might be affected by extreme flood events. Asia had the highest number of people living in the floodplain, and the number is expected to range from 232 million to 310 million by 2060.

In May 2021, Cyclone Yaas and Cyclone Tauktae attacked the east and the west coast of India. These two tropical cyclones caused strong winds and heavy rains, many coastal cities such as Mumbai suffered the strongest rainfall on record. Although the wind speed of Cyclone Yaas (about 110km/h) is only half of that of Cyclone Tauktae (about 220km/h), its impact was wider and soaked more areas of eastern India. One main reason was that the flood became compound under the multiple effects of storm surges, heavy rains, water level and sea level rises, and high tides.

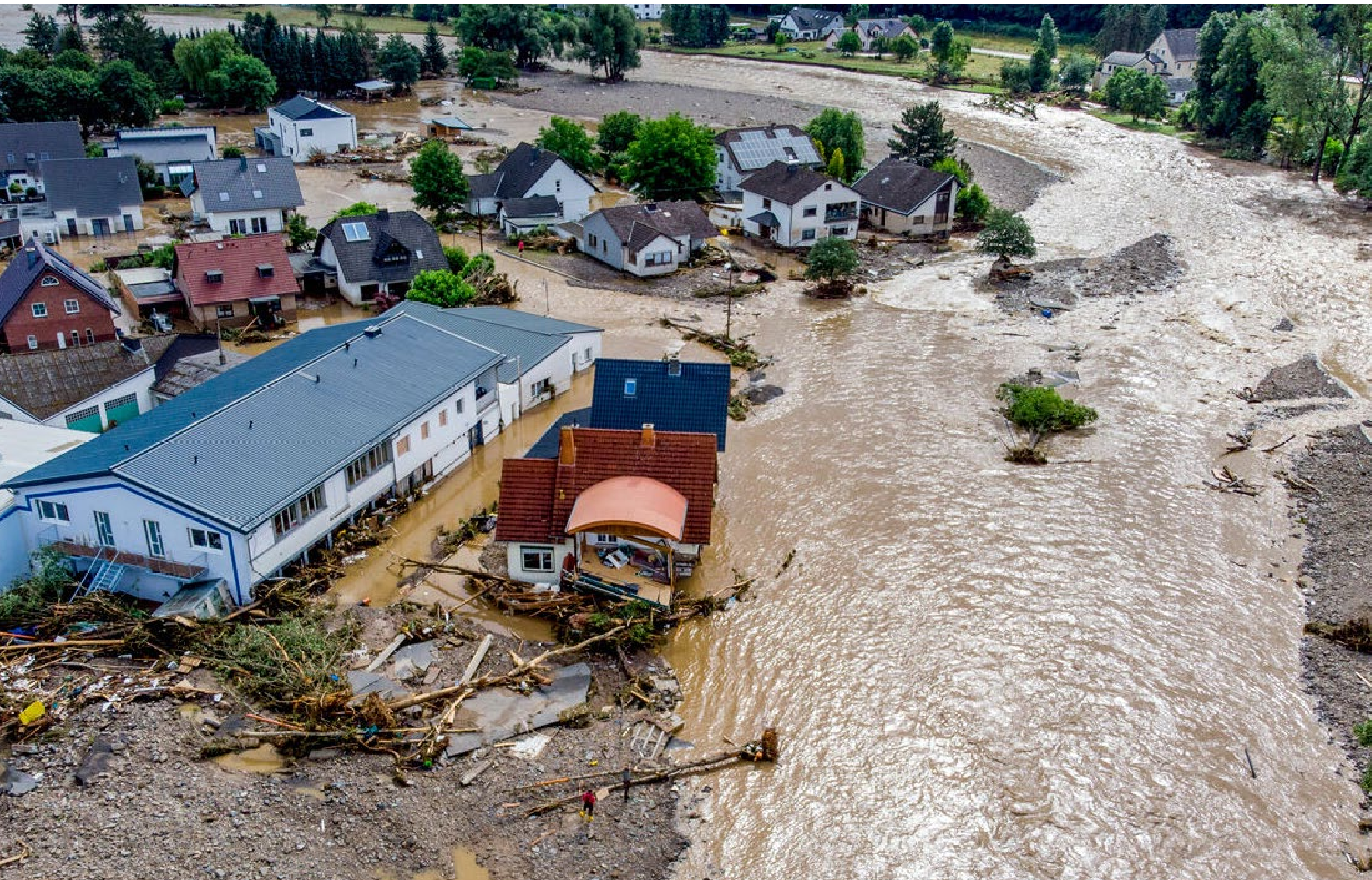
The climate change has increased tropical cyclones in the Arabian Sea year by year. Average precipitation before and after the monsoon has also been on the rise in the last two decades. Despite the total amount of monsoon rainfall decreased between 1950 and 2010 in India, the number of extreme rainfall events (above 150mm/d) is still growing. Sea level is currently rising more than twice as fast and will further accelerate if emissions are not sharply reduced. Many low-lying coastal cities and small islands will be exposed to risks of flooding annually by 2050, especially those without strong adaptation. Sea level rise, storm surges, heavy rains, and flooded rivers can overlap and damage coastal cities and their outlying regions. Mr. Koll underlined that population rise is indeed a threat multiplier that is often neglected by researchers, the growing population has multiplied the vulnerability of coastal areas to climate change.

For the way forward, the Indian Ocean will continue to warm, churning off more cyclones and floods along the west coast. When a disaster strikes, we can evacuate the affected residents, but are unable to to save the damaged ecosystems, infrastructure, houses, and cars. Therefore, we need to adopt a long-term vision and conduct coastal risk assessments to deal with compound extreme events and risks. To better monitor and forecast the changes, there is a need for governments to scale up relevant financial support and call for data and experience sharing through global partnership.

Mr. Koll also shared his views on the role of rainfall and sea level rise in future flood events. Sea level rise is a long-standing and in-progress process, and also an inherent impact factor regardless of cyclones. Coastal cities below sea level are predominantly vulnerable because discharge the flood water into the sea during flooding could be a problem. Cyclone rains usually lasts a few hours to a few days, and not necessarily affects cities and residents. Even so, rainfall-induced flooding may cause severe damage within a very short of time.

Lowering Risk by Increasing Resilience

On August 10, 2021, ICFM organized a webinar on "Lowering Risk by Increasing Resilience" to share experience and practices of various countries in flood management. The invited guests consisted of ICFM Chairperson, Prof. Slobodan P. Simonovic from Western University, Canada; Prof. Susan L. Cutter, Professor at the University of South Carolina and Director of IRDR International Centre of Excellence on Vulnerability and Resilience Metrics, the Unite States; and Prof. Chris Zevenbergen, Professor at the Department of Water Engineering of IHE Delft, and the Delft University of Technology, the Netherlands.



Slobodan P. Simonovic

ICFM Chairperson, Water Resources Specialist, Institute for Catastrophic Loss Reduction, Western University, Canada

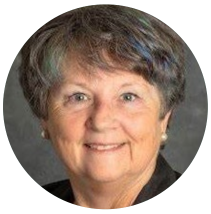
Lowering Risk by Increasing Resilience

Prof. Slobodan P. Simonovic pointed out that, almost 2 billion people around the world are currently exposed to the risk of flooding, and nearly 600 million of them are living in poverty. Climate change has increased the frequency and severity of floods over the past few years. Flooding has caused huge casualties and property losses yet its risk has been underestimated. The government should adopt a resilient approach to flood events and continuously update flood countermeasures. The objective of the webinar aimed at thought-provoking discussions on flood risk mitigation through increasing resiliency that has been a significant topic for new challenges and discourse in flood management.

Lyu Juan

Professor, China Institute of Water Resources and Hydropower Research (IWHR), China and the director of Research Center on Flood and Drought Disaster Reduction, Ministry of Water Resources, China.

Prof. Lyu stressed that, under the dual pressure of climate change and urbanization, extreme weather events occur frequently worldwide, tending to shift from single hazard to compound hazard. The risk is likely to increase in the future, so flood risk management strategies should be adjusted accordingly.



Susan L. Cutter

Carolina Distinguished Professor, Director, Hazards and Vulnerability Research Institute, Director, IRDR International Centre of Excellence on Vulnerability and Resilience Metrics (ICoE-VaRM), Department of Geography, University of South Carolina, the U.S.

Flood Risk, Vulnerability, and Resilience in the Americas

Prof. Susan L. Cutter focused on flood risk, vulnerability, and resilience in the Americas. Due to climate change, the frequency and severity of floods in the Americas have dramatically increased in 2021, including North America, Mexico and Colombia of Central America, and South America. Particularly, the continual floods in July 2021 caused casualties and economic losses to varying degrees across the Americas. Globally, extreme weather events has occurred frequently as well, and flood risks become more complex and dynamic. Therefore, an expansion of risk assessment framework is crucial for future flood risk management.

Prof. Cutter referred to the Global Risk Assessment Framework (GRAF) established by the United Nations Office for Disaster Risk Reduction (UNDRR). GRAF aims to improve the understanding and management of current and future risks at all temporal and spatial dimensions, and seeks to reveal the inter-dependencies of multiple risks and actors across systems, so as to reduce disaster risks. Prof. Cutter analyzed the flood risks faced by the United States in terms of hazard, exposure, and vulnerability in the GRAF. Flood risk mainly exist in coastal and urban areas in the United States. With the intensification of global warming, sea level rise aggravates the flood risk for coastal areas, threatening the safety of life and economics. Severe precipitation events become more frequent in the United States and directly lead to more flash flood events. Arid states are less resistant to heavy rainfall caused by hurricanes and typhoons, while low-lying cities find difficulty in quickly draining rainwater to avoid flooding.

Prof. Cutter explained the definition of vulnerability and the connotation of social vulnerability. Social vulnerability is one of the dimensions of vulnerability, identifying population characteristics that influence the social burdens of risk and empirically measures social disparities in disaster impacts, preparedness, response, and recovery. Prof. Cutter introduced the Social Vulnerability Index (SoVI) proposed by her research team as a system for measuring social vulnerability. Since there are many correlated indicators for vulnerability assessment, so information reflected by these indicators overlaps to a certain extent. Principal component analysis was used in the SoVI to reduce the dimensionality of vulnerability indicators. Through a mathematical approach, 42 variables were reduced to 11 independent factors that accounted for 76% of the variance, that is, a cumulative variance contribution rate of 76%. These factors were placed in an additive model without assigning weights to compute a summary score, that is, the SoVI. The results that varied among regions can be expressed using GIS. Prof. Cutter then built up a composite index system to assess the social vulnerability of American counties. The procedures included: 1) Identify factors of social vulnerability. According to the conceptual logic of social vulnerability, the impact is uneven in the affected/risk areas, to which vulnerable groups are usually more susceptible. For this reason, SoVI particularly emphasized the relevant elements that could reflect demographic and socio-economic characteristics. Factors that affect vulnerability include age, ethnicity, minority group, socio-economic status, resource accessibility, accommodation (housing density, type, etc.) and environment (infrastructure density, urbanization level, economic growth rate and vitality); 2) Sort out variables corresponding to these factors. In order to accurately describe the factors, appropriate variables should be selected to refine and render these factors into data. Through data calculations, social vulnerability can be quantified, reflecting differences between regions; and 3) Perform standardized calculation. Based on standardization on a 0–1 scale (0 represents high vulnerability and 1, low vulnerability), weight that indicates the priority was given to each variable, and a comprehensive score could be obtained. SoVI maps could be drawn to guide the risk prevention and mitigation measures at regional and local levels.

Exposure and vulnerability assessment is an important approach for risk assessment. Analyzing the temporal and spatial characteristics of these two factors is essential for risk assessment and management by providing a theoretical basis for forecasting and early warning, as well as prevention and mitigation. According to Prof. Cutter, social vulnerability means the potential for loss, so research should focus on three aspects: 1) Populations or regions that are prone to extreme natural events—potential exposure; 2) Capability of social systems to resist or recover from natural disasters—social resilience; and 3) Integration of potential exposure and social resilience in a given area. Potential exposure refers to the degree of exposure of social systems in a significantly changing climate. In research on social vulnerability to flooding, exposure is often expressed as the proportion of population affected by flooding, directly or indirectly, in potential areas. Social resilience refers to the capability of social systems to respond to and recover from natural disasters, covering social and economic status within the administrative units, industrial structure, population density and change, urbanization level, education, occupational structure, family structure, living conditions, age, medical conditions, unemployment rate, etc. For example, although the coastal areas of the United States are prone to natural disasters, they are highly urbanized and densely populated with frequent human activities, presenting relatively high social resilience to natural disasters. However, sensitive areas have a high level of social vulnerability to natural disasters because their social resilience is not strong enough to address the various problems and losses due to high potential exposure.

Prof. Cutter pointed out that resilience is closely related to flood risk management. Planning should be formulated to guard against flood and reduce flood risk and damage. In the past ten years, flood disasters have caused as much as 130 billion

U.S. dollars in property losses to various states. According to data released by the Federal Emergency Management Agency (FEMA) in 2021, hazard mitigation plans have been implemented or passed in most of the states. The results released by the U.S. Global Change Research Program in 2018 indicate that the national strategy for climate adaptation has been advancing, involving most of the coastal and lake areas. Regarding the economic aid after disasters, the U.S. government has extended the National Flood Insurance Program to homeowners, tenants, and enterprises, and provided certain subsidies to low-income disaster-stricken people who cannot afford insurance. However, the actual losses caused by some floods are still underestimated. If the flood is rated below the "national level", the affected groups can only obtain state-level assistance, which is actually not enough to truly get through the dilemma. FEMA also developed a regional risk assessment tool—National Risk Index (NRI). This online mapping tool can visualize natural hazard risk based on 18 natural disasters, with expected annual loss, social vulnerability, and community resilience. In addition to disaster frequency, NRI is also affected by post-disaster life and property losses, local demographic vulnerability, and local resilience. This tool comprehensively reflects the regional risk situation of natural hazards, and informs homeowners, tenants, and communities to be vigilant against natural disasters. For example, the risk is generally higher in big cities with more poor people, expensive properties, and insufficient preparedness for major disasters. Even if the frequency is low, only one flood may cause serious consequences.

At the end, Prof. Cutter highlighted the increasing systemic risks through the transition from single extreme events to compound events, and inequalities in flood disaster risk persist,. Flood control measures should be improved on the basis of better understanding the nature of flood risk, so as to address the impacts and losses brought by flood disasters.

Chris Zevenbergen

Professor, Water Engineering Department, IHE Delft, Department of Hydraulic Engineering, Faculty of Civil Engineering of the TU Delft, the Netherlands

Shifting Time Horizons in Flood Risk Management

Focusing on the challenges and opportunities of shifting time horizons in flood risk management (FRM), Prof. Zevenbergen talked about the three time domains involved when formulating FRM strategies and the long- and short-life time decisions. He proposed that there is a need to shift focus from adapting to slow changing conditions and preparing for singular, extreme events to (also) anticipating ‘abrupt’ changes and trends of extreme (clustering/compounding) events requiring to look further ahead both in terms of days (forecasting) and decades (projections/scenarios). In addition, long lead time and warning time of large scale flood control infrastructure are challenging governments to go beyond a traditional adaptive approach.

To feed the discussion, Prof. Zevenbergen reviewed the European flood events in 2021, and implied that most of the current flood control engineering projects in Europe were unable to cope with flooding of this magnitude. In particular, he shared the Dutch experience in this flood event. As the Skel, Maas, and Rhine estuaries to the sea, the Netherlands with a quarter of its territory below sea level has set a model with effective measures for flood control. Overarched by the government-led Room for the River program, Prof. Zevenbergen summed up the characteristics of the Dutch FRM from five aspects: 1) Through the Room for the River program with a lead time of 40 years, the new FRM paradigm has cast attentions to spatial planning for river systems, in addition to flood risk prevention; 2) Flood control management from a long-term horizon has been adopted by the government by considering long-term problems such as climate and hydrological changes. Flood control system therefore becomes more resilient and can effectively deal with risks associated floods; 3) Dual objectives of safety and spatial quality has been made. The Room for the River program effectively improves spatial quality while ensuring the safety of coastal cities to the greatest extent. It gives full play to the multiple functions of rivers, such as water supply, recreation, and urban landscaping, to produce long-term benefits; 4) Engagement and financial support of stakeholders and multi-level governments has ensured the operation of this huge project; and 5) The government is fully aware that flood control structures cannot be accomplished overnight. The 40-year lead time of the program guarantees the scale and quality of national flood control structures.

Prof. Zevenbergen shared lessons learned from the extreme floods event. Both intensity and frequency of extreme events are changing faster, thus making them more unpredictable. Traditional probabilistic models may not fit for compounding/clustering events any more. For disaster preparedness and prevention, despite Europe has an advanced Flood Awareness System that issued notifications four days in advance before the event. The problem was that the local areas did not receive effective information due to poor communication. In some countries, flood control facilities fall short of such flood disasters. This calls for infrastructure improvement, as well as maintenance, upgrade and renewal, so as to be prepared for disasters at any time. In short, flood resilience requires both preparedness and prevention to produce synergy.

Prof. Zevenbergen stressed that time horizons of flood risk management should be shifted. Through the development of flood risk management, there is a transition from reacting after events to preparing for events, and further to adapting to slowly changing climatic conditions through planning. However, this disaster has sounded the alarm for mankind: more extreme, more frequent, and more uncertain climatic conditions are anticipated. As climate change is intensifying, the strategy for adapting to slowly changing climate is no longer applicable. Prof. Zevenbergen said that there are three time domains of flood risk management: days, years, and decades. Flood risk management on a daily basis mainly relies on a relatively complete forecasting mechanism. Flood risk management within a time frame of years is possible to predict water level changes and sea level rise. If the time horizon is extended to dozens of years, past probabilistic models are no longer effective. A long-term flood control strategy such as the Room for the River program with a lead time of 40 years is very necessary for predicting the climate conditions in the next few decades and is also important for dealing with future climate disasters. In comparison, short-life term decisions (interventions such as building temporary barriers or maintaining critical infrastructure) have a high benefit-cost ratio. In addition, expected longer warning time provides more options for short-term interventions to enable complete disaster preparedness. Prof. Zevenbergen explained this point through a case study of Alexandria in Egypt. A record-breaking flood in 2015 inundated houses and caused casualties as Alexandria failed to respond properly at the time. An early warning system was deployed after this event. In the 2020 flood, the water level of rivers near the city was lowered to take over flood water on top of clearing drains in advance. Rescue teams were also fully prepared. With the help of the early warning system, Alexandria successfully weathered the flood. However, with a time horizon of decades, investment and construction of large-scale projects will be required. The lead time will be prolonged, lowering the ratio of warning time to lead time. Both complexity and uncertainty will increase. For this reason, the current general adaptive management is mainly based on short-term small changes, and the government is cautious about large-scale investment. In view of this, Prof. Zevenbergen raised the question: Given sufficient time, how should we shift the time horizons of flood risk management? He gave the answer through the example of building flood resilience in Dordrecht, the Netherlands.

Since maintaining the current coastline is costly due to sea level rise, the Netherlands plans to adopt a long-term strategy to shorten its coastline. It can be regarded as a transformative move, which is expected to take decades. But can the city afford it? The flood resilience project implemented by the port city of Dordrecht in the southwest of the Netherlands is a successful practice that effectively integrates flood prevention and preparedness. Low terrain makes Dordrecht prone to flooding all year round, so the city plans to improve its livability by redeveloping new types of residences areas in relatively higher terrains. The plan also incorporates flood preparedness and emergency response, so that such areas have the capacity to accommodate 60,000 emergency evacuees in the event of floods. In other words, this plan organically aligns disaster preparedness with urban development. Assessments indicated that building flood resilience will greatly reduce economic losses and casualties caused by extreme flood events. Therefore, disaster preparedness, as a means of flood risk management, should be equally emphasized as early warning.

Prof. Zevenbergen concluded with two messages. First, uncertainties are increasing as disaster risks such as floods are changing rapidly due to climate change. A longer-term horizon should be adopted for flood risk management, recognizing the necessity of long-life time interventions. Second, flood prevention and disaster preparedness should be organically integrated where possible, such as urban development. Technological advance will enable longer warning time and thereby expand options for short-life time interventions. However, there is still much room for improvement in disaster preparedness, which is currently inadequate to place restrictions on options.