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OVERVIEW

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Floods and the COVID-19 pandemic—A new double hazard problem

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Abstract
The coincidence of floods and coronavirus disease 2019 (COVID-19) is a genuine multihazard problem. Since the beginning of 2020, many regions around the World have been experiencing this double hazard of serious flooding and the pandemic. There have been 70 countries with flood events occurring after detection of the country's first COVID-19 case and hundreds of thousands of people have been evacuated. The main objective of this article is to assess challenges that arise from complex intersections between the threat multipliers and to provide guidance on how to address them effectively. We consider the limitations of our knowledge including "unknown unknowns." During emergency evacuation, practicing social distancing can be very difficult. However, people are going to take action to respond to rising waters, even if it means breaking quarantine. This is an emergency manager's nightmare scenario: two potentially serious emergencies happening at once. During this unprecedented year (2020), we are experiencing one of the most challenging flood seasons we have seen in a while. Practical examples of issues and guides for managing floods and COVID-19 are presented. We feel that a new approach is needed in dealing with multiple hazards. Our main messages are: a resilience approach is needed whether in response to floods or a pandemic; preparation is vital, in addition to defense; the responsible actors must be prepared with actions plans and command structure, while the general population must be involved in the discussions so that they are aware of the risk and the reasons for the actions they must take.

This article is categorized under:
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KEYWORDS
COVID-19, floods, management, multihazard, natural disasters, resilience

1 | INTRODUCTION

Since the beginning of 2020, people around the World have been living with the consequences of the global coronavirus disease 2019 (COVID-19) pandemic. Most people's mobility is severely restricted. They are instructed to maintain social distancing and to wear face masks in public places. Many have had to adjust to online working. Personal hygiene (especially frequent hand washing) has taken a prominent place in everyday activities. Links between the COVID-19 pandemic and water security, water management and water use are already being investigated (Keulertz, Mulligan, & Allan, 2020; Neal, 2020; Staddon et al., 2020). However, at the same time, many regions around the World have been experiencing a double, integrated hazard—serious flooding and a pandemic. Papers on floods and COVID-19 are now being produced and published in academic journals. This article includes references to a sample of relevant publications available so far (also in the early-online mode). Some papers are dedicated specifically to floods and COVID-19, in the national context (for China—Guo et al., 2020; Japan—Ishiwatari, Koike, Hiroki, Koda, & Katsube, 2020; United States—Shen, Chenkai, Yang, Anagnostou, & Li, 2021). Han and He (2021) noted that urban flash floods that are on the rise in the warming climate pose risks of COVID-19 spread. Other references extend beyond floods, for example, covering compound climate risks (Phillips et al., 2020) as well as drought, fire and flood (McDonald, 2020).

Every few days, people are adversely impacted by floods somewhere in the world. This seemingly bold, global, statement is backed up by evidence gathered by the Flood Observatory at the University of Colorado (http://floodobservatory.colorado.edu/Version3/MasterListrev.htm, accessed September 26, 2020). The Observatory detects these impacts by monitoring the abundance of water, via remote sensing, in normally dry places all over the world. The authors' personal experience will point only to regions of the world where they live and practice. Broader global information is provided in the following section.

1.1 | Canada

The spring season of 2020 brought a series of floods in Canada. Days of heavy rain caused flooding in parts of western Canada. Some areas of British Columbia recorded more than 370 mm of rainfall from 30 January to 01 February. Many regional districts declared a local state of emergency. As a result of this rainfall, there has been severe localized flooding, landslides, and rockfall damaging potable water infrastructure.

Evacuations were ordered in Alberta, Canada, after snow melt and ice jams caused rivers to rise from around April 25, 2020. The region declared a state of emergency on 26 April due to high water levels of the Athabasca, Snye and Clearwater rivers. The ice cover broke up at many locations, forming ice jams downstream. The ice jams raised water levels along the Athabasca and Clearwater rivers between 4.5 and 6 m at some locations (like Fort McMurray). Since the jams could release at any time, potentially impacted residents had to be evacuated.

In July, around 40 homes have been evacuated in Manitoba, Canada, amid fears a dam on the Little Saskatchewan River will fail. The dam was facing unprecedented flows following heavy rains over the period of time (July 1–3, 2020). Provincial and consulting engineers had indicated there was potential for a structural failure and authorities called for evacuations in the area. This evacuation came after a weather system had brought significant precipitation in southwest and west Manitoba. Some areas received record-precipitation of more than 200 mm during this period (July 1–3, 2020).

Spring flood season in Ontario, Quebec, and Canadian East Coast ended without the major flooding seen in the previous couple of years. Water levels in all areas decreased and returned to normal range before end of the spring. Officials remarked that water flows this year looked nothing like 2018 and 2019, which saw record flooding that destroyed homes and closed roads and highways. The annual River Watch Program was in place from March 9 and provided information on the status of rivers and the potential for ice jams and other flood issues. After 10 weeks in operation, the River Watch Program for the 2020 season terminated.

1.2 | Poland

In Poland, the meteorological and hydrological situation in 2020 was subject to large spatial and temporal variations. After two dry years, 2018 and 2019, this year saw a wet and warm February, but the winter precipitation was mostly rain not snow, so did not help in augmenting soil moisture in spring via snowmelt. This was followed by a dry April, leading to large areas of the country being on the verge of severe drought, but from May to September. Despite the overall drought, there were many heavy rainfall events that led to local inundation. In particular, the latter part of June was very wet in the south of Poland, with rainfall of 152 mm over 24 hr in Jodlownik (Malopolskie Voivodship).

This heavy rain increased water levels significantly in the Stream Stradomka—by five meters in less than 1 day. A large part of the Commune of Lapanow (County of Limanowa) was inundated, with considerable material damage to infrastructure (roads, homes) as well as to agriculture and animals. There were also landslides. At several gauging stations in the main rivers in Poland, the Vistula and the Odra, alarm stages were exceeded. On 21 June, the alarm stage was exceeded at 22 gauges in the Odra River Basin, while on 23 June, the alarm stage was exceeded at 11 gauges in the Vistula River Basin.

Although there were numerous flash floods caused by intense rainfall in the summer of 2020, the total flood damage in Poland in 2020 has been far lower than during the large summer deluges of 1997, 2001, and 2010. In contrast to these dramatic events, floods in 2020 did not cause fatalities. In 2020, inundations mostly affected the south of Poland (Podkarpackie, Malopolskie, Slaskie, and Dolnoslaskie voivodships), where the number of detected COVID-19 cases was consistently higher than in most other Polish provinces, so that there was a co-location of flood hazard and COVID-19 infection.

1.3 | United Kingdom

In the spring of 2020, the UK was impacted by a series of storms, the most serious of which was Storm Dennis from 15 to 19 February. On 16 February, severe flooding was reported across England. In the East Midlands, the River Soar flooded the town of Loughborough. Rail services were impacted by flooding between Derby and Long Eaton, affecting services between London, Derby, and Sheffield. Across the City of Nottingham, bus services of several companies were affected. Between Cambridge and Potters Bar, commuter trains to London were impacted by a tree on the line. Numerous outdoor events were canceled due to heavy rainfall and waterlogging.

In the West Midlands, a major incident was declared when river levels rose higher than the previous historic high of 2007 leading to damage to many properties and at least one death (https://news.sky.com/story/storm-dennis-river-wye-reaches-highest-level-for-200-years-11936537, accessed October 3, 2020).

In Wales, there were severe impacts with flooding at historically high levels. In the Rhondda (https://www.bbc.com/news/uk-wales-51517529, accessed October 3, 2020), more than 160 mm of rain was recorded in a 48 hr period. A major incident was declared by emergency services. Hundreds of homes were flooded across the region. In some areas, further damage was caused by flood water carrying cars and other debris. A further consequence was the occurrence of landslides causing further damage, which is indicative of the significant challenge to the UK transport infrastructure.

The City of Leeds had recently had new defenses implemented at a cost of £50 million with channel widening, raised defenses and movable weirs. These proved to be effective in lowering the level of the River Aire protecting over 3,500 vulnerable houses and businesses (https://twitter.com/EnvAgencyYNE/status/1228965407199039489?s=20, accessed October 3, 2020).

The UK Prime Minister convened emergency response meetings and subsequently announced tax relief for households and businesses. While flooding is often seen as being driven by physical factors it also has social and economic aspects. The severity of flooding depends on the unfavorable coincidence of specific temporal and spatial conditions with social and economic conditions. The COVID-19 pandemic can be described as a threat multiplier. Globally, changing conditions are considered to be flood threat multipliers too. We now have several threat multipliers that intersect with flood management challenges.

The main objective of this article is to assess the challenges that arise from complex intersections between the threat multipliers and provide guidance how effectively to address them. The following section of the manuscript discusses the multiple hazards and their nature. Section 3 presents the limitations of our knowledge, and Section 4 offers our view of flood management under the pandemic conditions. In Section 5, we offer some views of the future. The article ends with final concluding remarks and recommendations in Section 6.

2 | MULTIHAZARD: COINCIDENCE OF INDEPENDENT EVENTS OR CAUSE-EFFECT CHAIN?

Flooding is a serious problem that could complicate the significant and wide-ranging measures countries have taken to fight the coronavirus pandemic (see flooding examples in the introduction). Significant flooding adds a whole additional layer of challenge to full-blown assault against the pandemic. For example, community sandbagging is more difficult when everyone is practicing social distancing and people are in self-isolation. During emergency evacuation, practicing social distancing can be very difficult, even impossible. The economic damage being caused by the virus has also destabilized people's jobs and financial welfare, limiting their ability to absorb unexpected costs from flooding. Public security officials also warned that the risk of contamination from the virus means that emergency shelters may not be available for people who are forced out of their flooded homes. However, people are going to take action to respond to rising waters, even if it means breaking quarantine. This is an emergency manager's nightmare scenario: two potentially serious emergencies happening at once. 2020 has been one of the most challenging flood seasons seen in a while.

The coincidence of floods and COVID-19 is a real issue of the multihazard type, where the underlying hazards refer to independent events. However, in other cases, multiple hazards may not be independent. They may rather manifest a cause-effect chain, such as the disastrous Fukushima event on March 11, 2011, where a natural disaster (abundance of water due to a tsunami caused by a huge earthquake), caused a technological disaster (an unstoppable nuclear disaster at the Fukushima Daiichi nuclear plants).

Our world is filled with dynamic systems and epidemics are one such dynamic system. The more you look at the world around us, the more examples can be seen (populations, economies, climate, urbanization, and other examples). The system view is an effort to understand how dynamic systems operate (Simonovic, 2011). The goal behind system theory is to improve our decision-making processes to adapt to the dynamic attributes of complex systems. The systems view of epidemics is limited by our slow recognition of a change when it is happening and our slow response to that change.

On the other hand, a systems view of flooding states that flood losses are the result of interaction among three systems and their main subsystems: (a) the Earth's physical systems (e.g., the atmosphere, biosphere, cryosphere, hydrosphere, and lithosphere); (b) human systems (e.g., population, culture, technology, social order, economics, and politics); and (c) the constructed systems (e.g., buildings, flood defenses, roads and railways, bridges, public infrastructure, cultural heritage objects, cemeteries, and other).

Human systems include epidemics, and this is how a systems view must be used to integrate floods and pandemics. Potential solutions to integrated disaster management lie in (a) a definition of integrated disaster management as an iterative process of decision-making regarding prevention of, response to, and recovery from a disaster (in this case combined flooding and corona virus pandemic); and (b) a set of principles s elaborated in Simonovic (2011, p. 73).

There have been 70 countries (Figure 1) with flood events occurring after detection of the country's first COVID-19 case and the number of such countries keeps growing. Table 1 illustrates the dates of emergence of the first COVID-19 case in a country that was subject to a flood afterwards, that is, during the duration of the pandemic. There were 22 such countries in Africa, 25 in Asia, 8 in Europe, 8 in North America, 2 in Oceania, and 6 in South America, adding up to 70, globally (Russian Federation is counted once in the global total, but it is counted at two continents—Europe and Asia). The number of displaced people in some of these floods during the pandemic was very high. For example, in South China 634 rivers flooded and nearly 64 million people were affected. The death toll reached 219 and over 54,000 properties were destroyed (as of August 30, 2020). Over a hundred thousand people in Uzbekistan and Kazakhstan were

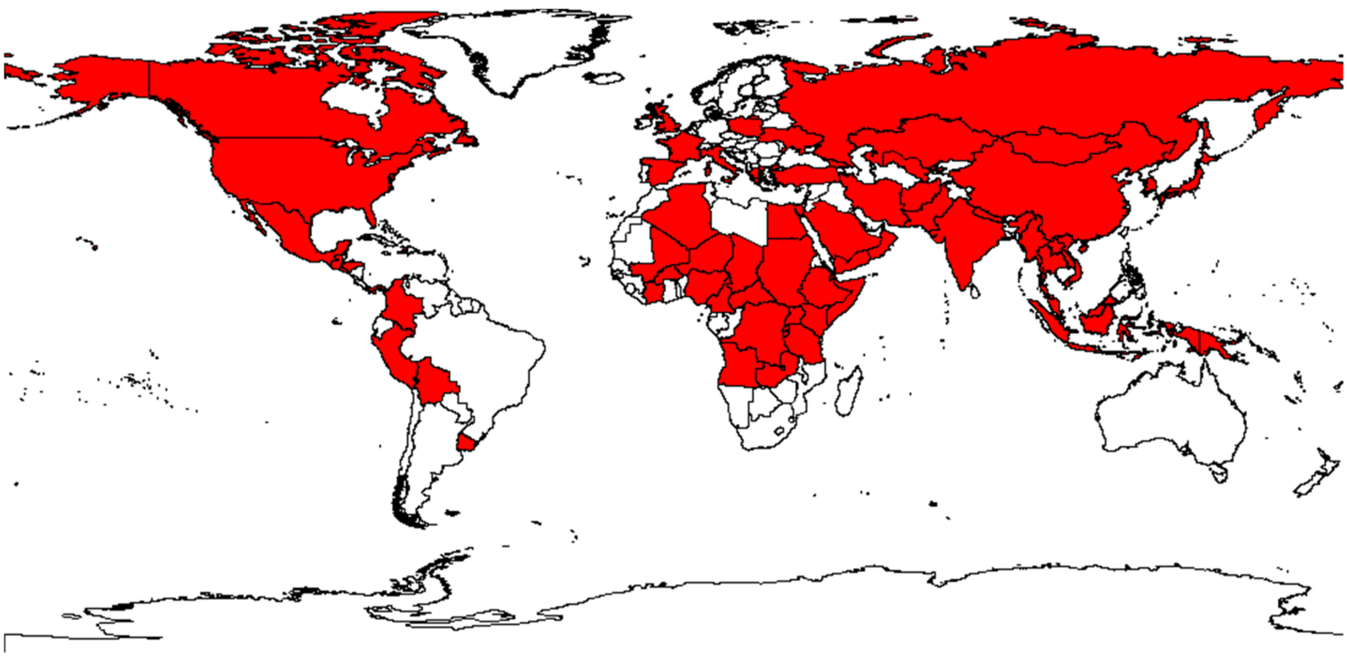


FIGURE 1 In 70 countries, flood events occurred during the pandemic, that is, after detection of the first COVID-19 case

TABLE 1 Dates of emergence of the first detected COVID-19 case in a country that was subject to a flood afterwards, that is, during the duration of the pandemic in 2020

Region	Country	Emergence of first COVID-19 case in 2020	Dates of flood events in 2020 after the first COVID-19 case
Africa	Algeria	25 February	16–18 May
	Angola	21 March	18–24 April
	Burkina Faso	9 March	19–26 April
	Burundi	31 March	19–26 April
	Cameroon	6 March	20 August
	Central African Republic	14 March	24–30 May
	Chad	19 March	20–26 April, 25 August
	Congo, D.R.	10 March	17 March–3 April, 16–20 May
	Djibouti	18 March	21–26 April
	Egypt	14 February	12–15 March
	Ethiopia	13 March	20–28 April, 8 August
	Ivory Coast	11 March	24–26 June
	Kenya	12 March	27 March–27 April, 25 August
	Mali	25 March	12 August
	Niger	19 March	8 August
	Nigeria	27 February	11 August
	Rwanda	14 March	19–26 April
	Somalia	16 March	20–28 April
	Sudan	13 March	3 August, 13 August
	Tanzania	16 March	24–27 April
	Uganda	20 March	20 August
	Zambia	18 March	4 March–24 April
Asia	Afghanistan	24 February	21 March–3 April, 26 August
	Bangladesh	7 March	19–20 May, 19 August
	China	A cluster of unexplained pneumonia cases was recorded in Wuhan in December 2019 that were caused by a new coronavirus, COVID-19	Multiple floods in June, July and August
	Georgia	26 February	1 August
	India	30 January	19–20 May and multiple floods in July, August and September
	Indonesia	2 March	24 February–10 March, 5–15 March, 31 March–3 April, 22–26 April, 22–30 may, 11–18 July
	Iran	19 February	24 February–10 March, 10–16 April
	Japan	3 January	29 June–5 July, 27–30 July
	Kazakhstan	13 March	1–11 May
	Laos	23 April	3 August
	Malaysia	25 January	20–25 June
	Mongolia	10 March	21–25 June
	Myanmar	23 March	15–30 July
	Nepal	24 January	20 August
	Oman	24 February	27–31 May

(Continues)

TABLE 1 (Continued)

Region	Country	Emergence of first COVID-19 case in 2020	Dates of flood events in 2020 after the first COVID-19 case
	Pakistan	26 February	6–17 March, 10 August, 26 August
	Russian Federation	31 January	24 April–11 May, 7–15 June, 17 July, 19–20 August, 20–24 September
	Saudi Arabia	2 March	6 August
	South Korea	20 January	29–30 July
	Sri Lanka	27 January	17–20 May
	Thailand	13 January	3 August, 24 August
	Turkey	11 March	23–25 June
	Uzbekistan	15 March	1–11 May
	Vietnam	23 January	22–26 April, 3 August
	Yemen	10 April	20–22 April, 4 August, 14 August
Europe	France	24 January	13 August
	Greece	26 February	9 August
	Italy	31 January	13 August
	Poland	4 March	21 June–5 July
	Russian Federation	31 January	20 June, 7–8 July
	Spain	31 January	1–2 April, 12 August
	Ukraine	3 March	22 June–5 July
	United Kingdom	31 January	16–17 February
North America	Canada	25 January	25–27 April, 13 August
	Guatemala	13 March	2–3 June
	Haiti	19 March	21–30 August
	Honduras	10 March	26 May-3 June
	Mexico	28 February	12 August
	Panama	9 March	25–29 July
	Trinidad and Tobago	12 March	9 August
	United States	20 January	22 March–3 April, 18–20 May, 22–30 August, 15–18 September
Oceania	New Caledonia	25 March	18–22 April
	Papua New Guinea	20 March	1–3 April
South America	Bolivia	10 March	2–10 March
	Colombia	6 March	14–16 March, 1–3 April, 5–18 July
	Ecuador	29 February	16–19 May
	Peru	6 March	28 March–2 April
	Salvador	18 March	2–3 June
	Uruguay	13 March	22–26 June

[a] *Source:* http://floodobservatory.colorado.edu/Version3/MasterListrev.htm and further, national, sources (last accessed September 24, 2020). https://en.wikipedia.org/wiki/COVID-19_pandemic_by_country_and_territory (last accessed September 24, 2020).

evacuated during a dam break flood. Some 81,000 people were evacuated in Somalia and Ethiopia and 78,000 in Democratic Republic of Congo during floods caused by heavy rainfall.

Many people affected by the flood were in close proximity during evacuation and in the emergency shelters, which may accelerate the spread of the pandemic and increase the difficulty of pandemic control.

Box 1 Flood in Uzbekistan and Kazakhstan

On March 13, 2020, the first four cases of COVID-19 in Kazakhstan were confirmed from people arriving from Germany and Italy. The first COVID-19 case in Uzbekistan was detected on March 15, 2020 (an Uzbek citizen returning from France). After the announcement of the case in Uzbekistan, Kazakh president Kassym-Jomart Tokayev announced a state of emergency in Kazakhstan, effective from 16 March to May 11, 2020 and closed the border with Uzbekistan.

Six weeks after the first COVID-19 occurrence in Uzbekistan, there was a major flood in both Uzbekistan and Kazakhstan, caused by a failure of Sardoba dam in Uzbekistan. The dam was completed in 2017 and had a storage capacity of 922 million cubic meters. The dam was built to irrigate agricultural lands in the Uzbek provinces of Sirdaryo and Jizzakh. Heavy rainfalls and high winds caused a dam wall to partially collapse, flooding large land areas in both neighboring countries. Hundreds of houses in both Uzbekistan and Kazakhstan were flooded.

In Uzbekistan, about 70,000 people from three districts in the Sirdaryo and Jizzakh regions (Sardoba, Mirzaabad, and Akaltyn districts) were evacuated. Two child fatalities were recorded. In Kazakhstan, more than 31,000 people from Maktaaral district in southern Turkestan province, which borders Uzbekistan, were evacuated.

See AGU Blogosphere at https://blogs.agu.org/landslideblog/2020/05/04/sardoba-dam-failure/ (last accessed September 25, 2020).

Box 2 Flood on the Yangtze River (China)

Wuhan is a megacity on the Yangtze River with a population of over 10 million, where COVID-19 was first detected at the beginning of December in 2019 and where the epidemic occurred in the winter of 2019/2020. Nearly all people in Wuhan received nucleic acid tests to control the COVID-19 epidemic. After a 2-month lockdown, the city reported no new cases of the COVID-19 for the first time on March 18. Recovering from the virus in its months-long battle, the city had reported no new confirmed COVID-19 cases for five consecutive days as of March 22.

In the middle of the recovery from COVID-19, starting on June 2, 2020, authorities in China issued alerts for heavy rainfall in the region for 41 consecutive days. The average precipitation in areas along the Yangtze River has reached to 754 mm for the period June 1–July 28, 2020 (China Meteorological Data Service Center, https://data.cma.cn/en/?r=site/index, last accessed September 30, 2020), the highest level since 1961. As of August 13, at least 219 people had been killed, 0.82 million people needed emergency assistance, 4 million people were evacuated, and nearly 64 million people were affected by the flooding (presentation of Mr. Zhou Xuewen, on August 13, 2020, Vice Minister, Ministry of Emergency Management and Vice Minister, Ministry of Water Resources, People's Republic of China).

According to Wang, Huang, and Fan (2020), the 30-day cumulative precipitation with a 1,000-year return period was observed in Anhui, Guizhou and Sichuan Provinces. The highest observed 30-day cumulative precipitation in 2020 was 1,221 mm, in Anhui Province, while the highest one in 1998 was 1,028 mm, in Jiangxi Province.

Flooding destroyed nearly 0.4 million homes and damaged 5 million hectares of farmland. According to the Ministry of Emergency Management of China, it is estimated that direct economic losses exceed USD $25 billion.

Professional emergency management teams and the People's liberation Army participated in the flood control. Three Gorges Project (TGP) also played a key role in controlling the flooding. Until August 21st, it intercepted floods of 30,000 m^3/s on nine times, floods of 50,000 m^3/s on five occasions and on August 20, 2020, the largest flood since the construction of 75,000 m^3/s.

There have been major floods on Yangtze River in 1931, 1954, and 1998. Improved forecasting and combined green and gray infrastructure protection (including the Three Gorges Dam) has improved the situation: the 1931 flood with the a volume (60 days) of 435.66 billion m^3 recorded 145,000 fatalities and 330 dike breaches; the 1954 flood with a flood volume of 489.95 billion m^3 recorded 33,000 fatalities and 63 dike breaches; the 1998 flood with a volume of 417.45 billion m^3 recorded 3,650 fatalities in the Yangtze River Basin (Kundzewicz, Su, Wang, et al., 2019) and only one dike breach along the main stem of the Yangtze river. This year's flood has yet to have a volume confirmed, but recorded the smallest number of fatalities at 219 (Xia, 2020).

Boxes 1 and 2 present illustrative examples of 2020 floods in Uzbekistan/Kazakhstan and China (Yangtze River, Hubei Province) amidst the pandemic that was on the dynamic rise in the countries affected by flooding.

Some other locations around the world experienced even more complex situation where the pandemic and flooding were affected by additional hazards. Locusts, COVID-19 and deadly flooding posed a "triple threat" to millions of people across East Africa in the spring. The combined threats imperiled a region that was already home to about 20% of the world's population of food-insecure people, including millions in South Sudan and Somalia. Lockdowns imposed for the COVID-19 pandemic slowed efforts to combat the locusts, especially imports of the pesticides needed for aerial spraying that is seen as the only effective control. The spring floods in parts of East Africa killed nearly 300 people and displaced 500,000, slowing locust control work and increasing the risk of the virus' spread, according to the International Federation of Red Cross and Red Crescent Societies.

Internet search engines deliver hundreds of thousands of entries for "COVID" + "flood," some of which do not pertain to abundance of water, as the term "flood" illustrates abundance in general (e.g., flood of papers, flood of patients, flood of COVID-19 liability claims, flooding the world with fraud). Nevertheless, there have been many entries in media sources of considerable relevance and interest that illustrate a broad range of issues, related to floods and COVID-19, such as the sample compiled in Table 2.

In many countries, pre-existing flood disaster management plans deal with the individual disaster scenarios. The problem is that these plans do not account for a pandemic happening at the same time. The year 2020 was "unprecedented." It has been noted that during 2020 flooding emergency managers were less focused on the pandemic response than the immediate danger from flooding, trying to minimize immediate loss of life.

In spite of the huge challenges from overlapping disasters, there are some reasons for hope. The pandemic did not change the capability to remotely monitor the environment for catastrophic events and to warn the public in a timely manner. Also, the pandemic led to the activation of emergency operation centers before flooding started, shortening significantly the response to sudden events like floods. The coronavirus will be difficult to avoid for the foreseeable future. But as has been shown above, when an additional disaster such as flooding takes place, the more immediate threat to life was dealt with first.

3 | UNKNOWN UNKNOWNS

Floods have struck a myriad of times since the very beginning of human civilization, hence this hazard is well known, even if short-term memory syndrome can be observed. There are ample national flood risk-reduction activities, such as investments, legislation, and research that are typically triggered by disastrous flood events. However, the interest of decision makers and the broad public and the willingness to pay decrease with time, even after just a few years. This observation is valid for any economic, political, and social system. Hence a daily prayer of a flood manager may extend beyond "give us this day our daily bread" to include "and give us a little flood from time to time," as a reminder.

The European Union's Floods Directive was triggered by disastrous large-area floods in Europe in August 2002. This legal act sets out national obligations related to implementation of the Directive in all 27 EU Member States which enhance the lasting commitment to reducing flood risk, which is conceptualized as a combination of hazard, exposure, and vulnerability. The Directive guards against short-memory syndrome.

In China, severe floods hit the basins of several major rivers in 1998 and since then USD $294 billion has been invested up to 2017 to enhance flood control systems, accounting for more than one third of the total investment in water engineering, Figure 2, as a consequence, the length of dikes was increased from 76,532 to 201,124 km, and reservoir capacity increased from 493 billion to 932 billion m^3. This sustained investment in the flood control system breaks the previous cycle of short-memory syndrome. This is because of the legal guarantee of the Flood Control Law of PRC enacted in 1998 and rapid economic growth in the 21st century.

In the context of the double calamity, a pandemic and floods, it is worth considering the concept that became well known after being used by Mr. Donald Rumsfeld, the US Secretary of Defense, in his news briefing given on February 12, 2002 in reference to the lack of evidence linking the Iraqi government and t weapons of mass-destruction. Mr. Rumsfeld spoke of known unknowns ("we know there are some things we do not know") and unknown unknowns ("we do not know we do not know"). Actually, these concepts are older than the famous use by Rumsfeld by more than two decades. As indicated by Vit Klemes (2002), "unkunk" (unknown unknown) was a label used by the US Air Force for unpredictable problems (Linstone, 1978). In his oral contribution to the Kovacs Colloquium delivered in 1996, a long time before use by Mr. Rumsfeld (see Klemes, 2002), Klemes extended the notion. In addition to kunks (known unknowns) and unkunks (unknown unknowns), he devised a category of skunks: unkunks represented as skunks that is "knowns" that stink. In the modern parlance, perhaps they could be baptized "postknowns." Klemes (2002, p. 29) issued the following recommendations: "Kunks should be treated with rigor. Unkunks should be treated with care. Skunks should be avoided."

The COVID-19 pandemic affected different countries with different level of shock, seeming to be a real unknown unknown for many nations and governments. However, for some experts, nations and governments, COVID-19 was more of a known unknown, since a SARS CoV pandemic had happened before. The WHO had also warned of the likely significant impact of the pandemic. Likewise, the UK National Register of Risk had identified a pandemic as the most likely and largest risk. Nevertheless, there was acute lack of prior knowledge about the characteristics of the virus and the spatiotemporal spread of the epidemic. The jury is still out as to the optimal policy for COVID-19 management. Different countries demonstrated different attitudes from business-as-usual to (obligatory or recommended) social distancing, self-isolation, and lockdown, though at different stages of development of the pandemic. In many countries a state of emergency was introduced. Probably countries impacted by SARS (China, Canada, South Korea) were better prepared for COVID-19. This could demonstrate the value of hindcast and experience as pointed out above in terms of short-memory syndrome. There is also a speculative hypothesis that nations where tuberculosis vaccination was obligatory are less susceptible to COVID-19.

WHO provided "Critical preparedness, readiness and response actions for COVID-19" guidance (WHO-COVID-19-Community_Actions-2020.4-eng.pdf, last accessed December 22, 2020) that focused on control of COVID-19 by slowing down transmission of the virus and preventing associated illness and death. Four transmission scenarios are considered in supporting countries in selecting and tailoring their approach to the local context: (a) no cases; (b) sporadic cases (one or more cases imported or locally detected); (c) clusters of cases (clustered in time, geographic location, and/or common exposure); and (d) community transmission (larger outbreaks of local transmission, detected through an assessment of large numbers of cases not linked to transmission chains, large numbers of cases from sentinel lab surveillance, or multiple unrelated clusters in several areas of the country).

WHO guidelines recommend the following global strategies:

- Mobilization of all sectors and communities to ensure participation in the response and in preventing cases through hand hygiene, respiratory etiquette, and individual-level physical distancing.
- Controlling sporadic cases and clusters and preventing community transmission by rapid finding and isolating.
- Suppressing community transmission through context appropriate infection prevention and control (population-level physical distancing, and appropriate and proportionate restrictions on nonessential domestic and international travel).
- Reducing mortality by providing appropriate clinical care for COVID-19 patients and ensuring the continuity of essential health and social services.
- Development of vaccines and therapeutics.

In spite of differences between the countries, it is quite clear that all countries should increase their level of preparedness and response to identify, manage, and deal with new cases of COVID-19. Response to different public health scenarios is required recognizing that there is no one-size-fits-all approach to managing the pandemic.

4 | FLOOD AND COVID-19 MANAGEMENT

Both for flood and pandemic, we can state that such a calamity cannot be prevented completely, but certainly we can, and must, reduce the likelihood and the impact. As out pointed earlier, the pandemic amplifies the risk related to weather extremes, including floods. A flood may complicate pandemic responses, including health risk for the first responders and for the evacuees. This creates additional challenge to decision makers, stakeholders, and those affected and concerned. Shifting resources is needed, worldwide, to combat the pandemic and to buffer the economy.

It is necessary to review and, if necessary, modify the existing action plans, procedures and protocols, in an ad hoc way, to ensure they are appropriate for the pandemic. There are contrary conditions, as the epidemic requires social distancing and isolation, while flooding requires collaboration. In Bangladesh, despite humanitarian assistance and government organizations being prepared for flooding as well as a pandemic, in the densely crowded camps in Cox' Bazar,

TABLE 2 A sample of media messages, related to floods and COVID-19, illustrate a broad range of important issues

Message	Media source
Floods are not unusual in Assam, particularly during monsoons. However, in 2020, it is not just the threat of rising waters that is facing the people of the state. The looming threat of COVID-19 in the flood relief camps set up by the administration, threatens to push the already-vulnerable to higher risk. "When the waters threaten to take away your life, swallow your land, your animals, the focus is to just survive. Now there will be two things threatening us." (June 3, 2020)	https://india.mongabay.com/2020/06/with-floods-and-covid-19-assam-faces-a-dual-threat/
The workers were brought in from Florida and Texas to Michigan after the May 19 flood. Approximately 50 tested positive while in Michigan. There were claims that the workers were forced to work without sufficient personal protective gear and lived in crowded hotel rooms. (July 25, 2020)	https://www.michiganradio.org/post/group-asks-greater-covid-19-protections-workers
Mr. Chandrababu Naidu, former Chief Minister of Andhra Pradesh and current leader of parliamentary opposition expressed concern that the troubles of the common people in the state were multiplying day by day under the inefficient rule of the government. He stated that the government's failures and wrongdoings were exposed during the coronavirus relief measures and also floods. No relief was provided to the victims. Mr. Naidu accused the ruling party of "betraying all sections of population." (October 11, 2020)	https://www.thehansindia.com/andhra-pradesh/covid-flood-exposed-governments-inefficiency-tdp-650707
Two companies brought the workers from Florida to mid-Michigan after catastrophic floods in the spring of 2020. After a COVID-19 outbreak among workers who helped with re-building efforts in Midland and Bay counties, companies are facing a lawsuit. Allegedly, the companies failed to take proper workplace safety precautions, after luring the workers to Michigan with false claims about workplace safety. They improperly discharged workers who had been exposed. The lawsuit says the defendants then sent the workers home, spreading the risk of COVID-19 to their families and to other communities. According to the lawsuit, at least 17 workers contracted COVID-19 (two have been critically ill), and some spread it to their families. (October 14, 2020)	https://www.michiganradio.org/post/companies-sued-over-covid-19-outbreak-among-flood-recovery-workers
Hyderabad flood victims were shifted to 165 rescue and relief camps. Flood victims, who exhibited symptoms that could be related to COVID-19 were tested and some tests gave positive results. Those identified as COVID-19 positive were shifted to government hospitals for treatment. In addition to the health camps, functioning round the clock, also 42 mobile health centers were set up, to reach out to people in flood hit areas who did not require evacuation. Doctors, nurses and other health department staff, who have been working hard for controlling COVID-19, now stepped up to assist flood victims. (October 18, 2020)	https://www.deccanchronicle.com/nation/in-other-news/181020/hyderabad-flood-victims-test-positive-for-covid-in-relief-camps.html

which shelter some 900,000 Rohingya refugees (Ishiwatari et al., 2020), some families were "turned away at the door of a shelter, because they didn't have enough face masks for every family member."

It is necessary to identify hotspots related to pre-existing exposure and vulnerability in informal urban/suburban settlements, where marginalized people live and where flood protection cannot be provided. Both floods and the pandemic "cluster around poorer, racially marginalized populations so much that some have referred to inequality as a comorbidity" (Kramarz, 2020). COVID-19 exacerbates the "typical" morbidity concerns related to floods (injuries, gastric problems, PTSD—Post-Traumatic Stress Disorder). Lockdown increases the impact of mental health challenges leading to long-term health implications and exacerbates the factors that lead to greater domestic violence.

Some practical examples of managing floods and COVID-19 can be already extracted from this year's flood season. The Province of Manitoba (Canada) for example provided a high water response activity guide for COVID-19 adaptation (https://www.gov.mb.ca/emo/pdfs/adaptations-to-high-water-response-activity.pdf, last accessed September 15, 2020). For sandbagging activities, which is a common measure for temporary diking in Manitoba, the guide

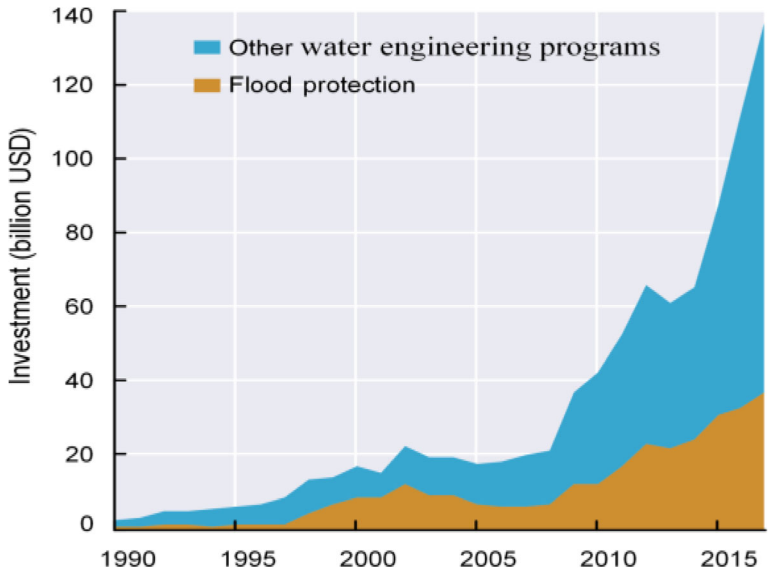


FIGURE 2 Investment in flood protection and other water engineering programs since 1990 in China (in 2015 USD)
Source: After Du, Cheng, and Huang (2019)

recommends: (a) for small dikes—the process using a 2-person team where individual workers will maintain separation by being at alternate locations in the process while ensuring a minimum 2 m spacing between them; (b) for large dikes—the process using a multiperson team (carousel) where one worker will take a sandbag from a stockpile and proceed to dike area along the circular path and place the sandbag at the dike. The workers will move to the right or left about 3–4 m following the circle and ultimately returning to stockpile while maintaining space between them. Workers will continue to move the line and sandbags along to complete the dike in a "carousel" fashion (Figure 3).

In Japan, the usual approach to housing people displaced by disasters in primary school gyms had 200–300 people crammed into an area with inadequate ventilation and limited access to toilets (Reynolds, 2020). Since each person is allotted space of about 1.6 m^2 for one straw "tatami" mat, this leaves little room for social distancing. Marking out spaces to keep households two meters (6 ft) apart means each shelter can accommodate fewer evacuees. Officials are trying to identify additional shelter sites, from government facilities to hotels and inns, with mixed success (Reynolds, 2020).

The Union of Concerned Scientists in the United States (https://www.ucsusa.org/resources/maps-flooding-risk-and-covid-19, last accessed September 16, 2020) provided maps of flooding risk and COVID-19 (Figure 4). These maps compare areas at risk of flooding with two different COVID-19 scenarios between April 13 and May 16. For example, in one scenario (Figure 4a), social contact within each county decreases by an additional 20% each week until the number of cases in that county starts to decrease. In the second scenario (Figure 4b), social contact decreases by 40% every week until cases decrease. The modest reduction in social contact in the first scenario results in more than 600,000 cases of COVID-19 that also carry a risk of moderate or major flooding. The second scenario results in roughly 170,000 cases of COVID-19 in areas also at risk of flooding—a reduction of more than two thirds.

5 | PROSPECTS FOR THE FUTURE

Flood hazard is clearly nonstationary. It varies with the climate as well as land-use and land-cover changes. However, projections for the future, even if largely uncertain, indicate increasing flood hazard and risk in many areas. Willner, Levermann, Zhao, and Frieler (2018) postulate that considerable adaptation efforts are required in many countries to preserve future high-end river flood risk at present levels.

There is evidence of regional predisposition (in a probabilistic, rather than a deterministic sense) to abundance of water, related to the climate variability, described by indices of the oscillation in the ocean–atmosphere system. Kundzewicz, Szwed, and Pinskwar (2019) published a comprehensive literature review indicating the links between the climate variability indices, such as ENSO, PDO, NAO, and AMO and characteristics of abundance of water (intense precipitation, high river flow, flood damages). Apparently, globally, the oscillation pattern that has strongest links with floods is ENSO (*El Niño*—Southern Oscillation). During the warm ENSO phase (*El Niño*), there is predisposition to floods in such regions as South America, California and Arizona, parts of Asia and central east Africa, while during the cold ENSO phase (*La Niña*), there is predisposition to floods in Australia and many regions in Africa.

The number of flood disasters has been increasing very rapidly, more than threefold, since 1980 (ICHARM, 2020). What is also striking is that more than three-quarters of the economic losses are reported from high or upper-middle-income countries, whereas more than 80% of the human losses have occurred in lower-middle or low-income countries. Disasters inhibit growth while growth amplifies disaster damage. To solve these problems, it is essential for nations to strengthen disaster resilience and achieve sustainable development. Multihazard conditions as demonstrated by flooding and virus pandemic create and amplify disasters that require a different approach—a paradigm change. There are practical links between integrated disaster management and sustainable development leading to reduction of disaster losses and re-enforcing resilience as a new development paradigm. There is a need for change in disaster management approaches, moving from disaster vulnerability to disaster resilience; the latter being viewed as a more proactive and positive approach. Hazards may be combined and increasing and at the same time they erode resilience. In the past, standard disaster management considered arrangements for prevention, mitigation, preparedness and recovery, as well as response. However, today more than ever we need a substantial progress in establishing the role of resilience in sustainable development. Multiple examples of flooding in 2020, during the pandemic, reveal links between attributes of resilience and the capacity of complex systems to absorb disturbance while still being able to maintain a certain level of functioning. Diversification of flood management strategies can pave the way toward more flood resilience (Hegger et al., 2016; Priest et al., 2016). Unfortunately, we manage neither by keeping destructive waters away from people at all times (via structural defenses—levees, bypass channels, storage reservoirs) nor keeping people and wealth away from destructive waters (via flood-risk prevention—including relocation and zoning, i.e., prohibiting or discouraging development in risky areas). Hence, it is necessary to embark on a diversified portfolio of flood-risk–management approaches, including flood-risk mitigation, preparation, and recovery, to maximize the net effect of a combination of strategies (Kundzewicz, Hegger, Matczak, & Driessen, 2018).There is a need to focus more on action-based resilience planning. Disasters do not impact everyone in the same way. It is clear that the problems associated with sustainable human wellbeing call for a paradigm shift.

Resilience—in the context of this discussion—is defined as: "the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous events in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions" (Agrawal, Elliott, & Simonovic, 2020; Simonovic, 2016, 2020; Simonovic & Arunkumar, 2016; Simonovic & Peck, 2013).

Ansell and Boin (2019) use Pragmatism (practical and commonsense) principles to deal with strategic crisis management arguing that crisis management is not rational when we have "unruly problems." Real crisis management (preparation and response) is based on a few simple principles of Pragmatism: (a) constant calibration; (b) antidualism;

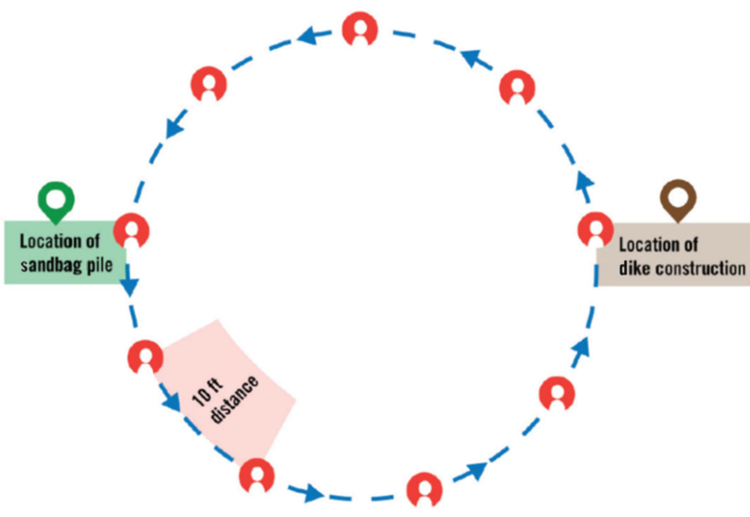
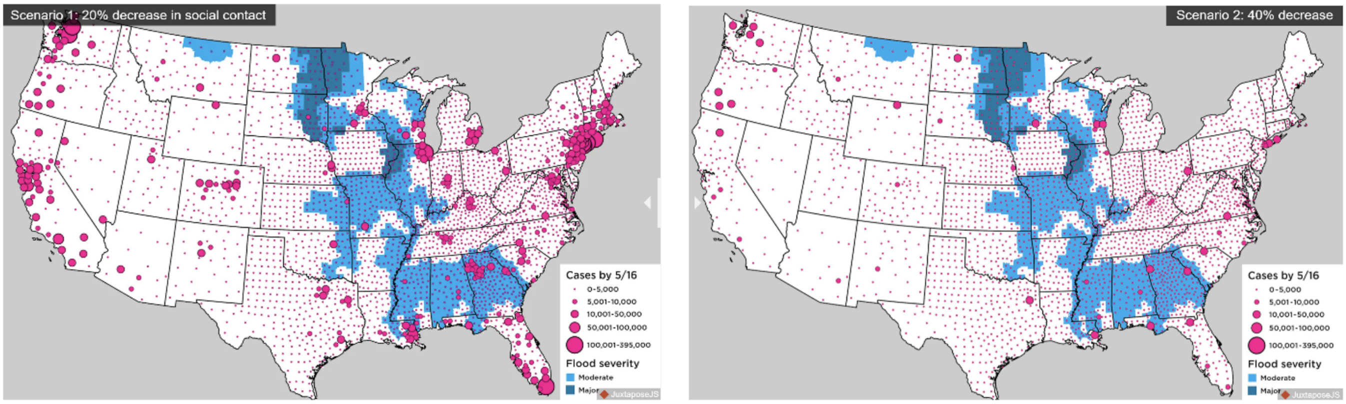


FIGURE 3 Large dike sandbagging using a multiperson team—carousel
Source: After https://www.gov.mb.ca/emo/pdfs/adaptations-to-high-water-response-activity.pdf, last accessed September 15, 2020



(A) (B)

FIGURE 4 Maps of flooding risk and COVID-19 (a) social contact decrease by 20%; (b) social contact decrease by 40%
Source: https://www.ucsusa.org/resources/maps-flooding-risk-and-covid-19, last accessed September 16, 2020

(c) experimentalism (adaptive decisions); and (d) bricolage (creating from multiple elements). The Pragmatist perspective offers an alternative approach that fits the resilience definition as used in this article: Treat the changing picture of the situation as a hypothesis and test it continuously against incoming information and avoid making irreversible decisions.

Some qualitative flood resilience work has been done by Wardekker et al. (2020) with a focus on the presentation of a practical tool that helps diagnose choices made in resilience-building, making them transparent and explicit. The Resilience Diagnostic Tool presented in this article aims to function specifically as a learning tool. The tool is process-based and qualitative: it uses guiding steps, frameworks, and questions to perform the assessment. Therefore, it does not require any software or detailed data sets, what may be one of the serious deficiencies of the tool. The Resilience Diagnostic Tool employs a generic three-step approach (commonly used by other qualitative and quantitative tools): (a) The first step reflects on choices in the goals of resilience-building by examining the local situation and goalsetting; (b) The second explores choices made: which aspects of resilience (resilience principles) are emphasized? This is done for both the current situation (baseline) and proposed plans, measures, or policies for resilience-building (interventions); and (c) The third reflects on consequences of these choices: whether the interventions match the goals and potential side-effects.

Following the definition of resilience presented above and experience obtained by its implementation in the context of flooding caused by climate change (Peck & Simonovic, 2013; Simonovic & Peck, 2013), we are recommending its easy expansion to the multiple hazard conditions of flooding under COVID-19. While traditional flood management focuses on the reduction of prehazard vulnerabilities, disaster resilience is achieved by introducing adaptation options that enable the community to adapt to the impacts of hazards and enhance the ability of the physical, social, economic sectors to function in the event of a disaster. These adaptation options help the system components to cope with, and recover from hazard impacts in order to return to a predisaster level of performance as rapidly as possible.

The quantitative measure of resilience is based, as previously stated, on two basic concepts: level of system performance and system adaptive capacity as illustrated in Figure 5.

Generic presentation of system performance used for the quantification of resilience is shown in Figure 5a. The area between the initial performance line P_0 and performance line $P(t)$ represents the loss of system performance, and the shaded area under the performance line $P(t)$ is used as the representation of the system resilience. By integrating the shaded area in Figure 5a and then normalizing its value, the system performance is converted into system resilience shown in Figure 5b. In Figure 5, there are three possible outcomes in resilience simulation: (a) resilience returns to predisturbance level (solid black line in Figure 5a,b); (b) resilience exceeds predisturbance level (dashed blue line in Figure 5a,b; or (c) resilience does not return to predisturbance level (dashed and dotted red line in Figure 5a,b). For example, proactive measures will result in the red curve and reactive measures may result in the blue curve. System adaptive capacity is defining the shape of the resilience curve which offers more insight into dynamic performance of the system under disturbance through the four values of robustness, redundancy, resourcefulness and rapidity, known as 4Rs (Bruneau et al., 2003; Cutter et al., 2008).

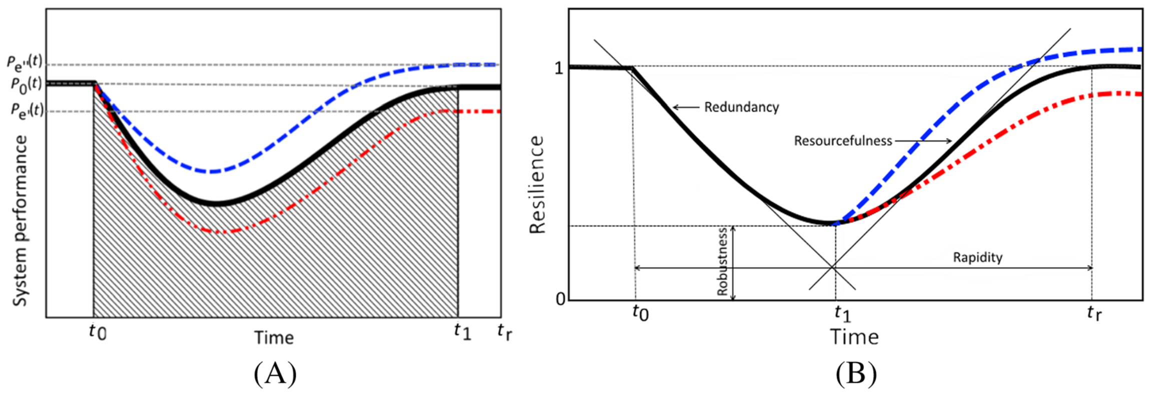


FIGURE 5 Graphical illustration of resilience: (a) system performance; (b) resilience. Black line shows full recovery to prehazard system performance. Red line shows partial recovery. Blue line shows improved system performance

The main characteristics of resilience (4Rs) are: (a) robustness, that is the strength or the ability of the system to resist hazard-induced stresses (e.g., flood protection measures); (b) redundancy, that is the ability of a system to provide uninterrupted services in the event of a disruption (e.g., a twinned pipeline); (c) resourcefulness, that is the utilization of materials (monetary, technological, informational, and human resources) to establish, prioritize and achieve goals (e.g., mobilization of disaster management funds); and (d) rapidity, that is the capacity to return the system to a prehazard level of functioning as quickly as possible. The slope of the declining section of the resilience curve in Figure 5b provides insight into system redundancy and slope of the rising section of the resilience curve offers the information about system resourcefulness. Robustness of the system and rapidity are clearly illustrated with the system performance level at time t_1 and difference in time between t_0 and t_r, respectively.

The implementation of quantitative resilience assessments is done by using system dynamics simulation. The quantification concept is easily expanded to assess the spatial distribution of resilience by implementing simulation process at various locations in space and then by connecting them creating a dynamic map that captures the temporal (simulation in time) and spatial (integration in space) quantitative characteristics of the resilience measure. Simulation modeling (for obtaining system performance and resilience in time) is integrated with GIS (Geographic Information System) processing to obtain resilience values in space. The same quantitative resilience concept has been successfully extended to multiple hazard situations in the infrastructure management (Kong, Simonovic, & Zhang, 2018).

Evidently, resilience is a proactive means of disaster management making it more desirable for implementation. It is dynamic. It offers quantitative measure to support decision-making in evaluation of various adaptation measures. It has been already tested in the single hazard case (Simonovic & Peck, 2013) of flood management. It has been also extended to multiple hazard case in infrastructure management (Kong et al., 2018) affected by hurricane and flooding. The methodology used by Kong et al. (2018) can be directly implemented in considering flood disasters under COVID-19.

Lessons for the future are:

- A resilience approach is needed whether in response to floods or a pandemic. This means accepting that the event will occur and ensuring that the resilience is enhanced and impacts are mitigated. It also means accepting that the socioeconomic system will not necessarily return to antecedent conditions, rather the system needs to adapt to a "new normal" (possible outcome shown in Figure 5 in blue and red).
- Preparation is vital, in addition to defense. The responsible actors must be prepared with actions plans and command structure, while the general population must be involved in the discussions so that they are aware of the resilience level and the reasons for the actions they must take to increase it.
- As well as understanding the engineering of defenses and how hydrology predicates events and their scale, it is vital to understand people's behavior. Only with this can resilience be communicated and only with this can the population be ready to respond to the events. Societies are diverse in many ways and within a population there are widely varying attitudes to risk, resilience and uncertainty. This means that flood management research must continue to include engineering and environmental science, but behavioral science and risk communication is also a vital component. The proposed quantitative resilience allows effective communication of risk and impacts of various

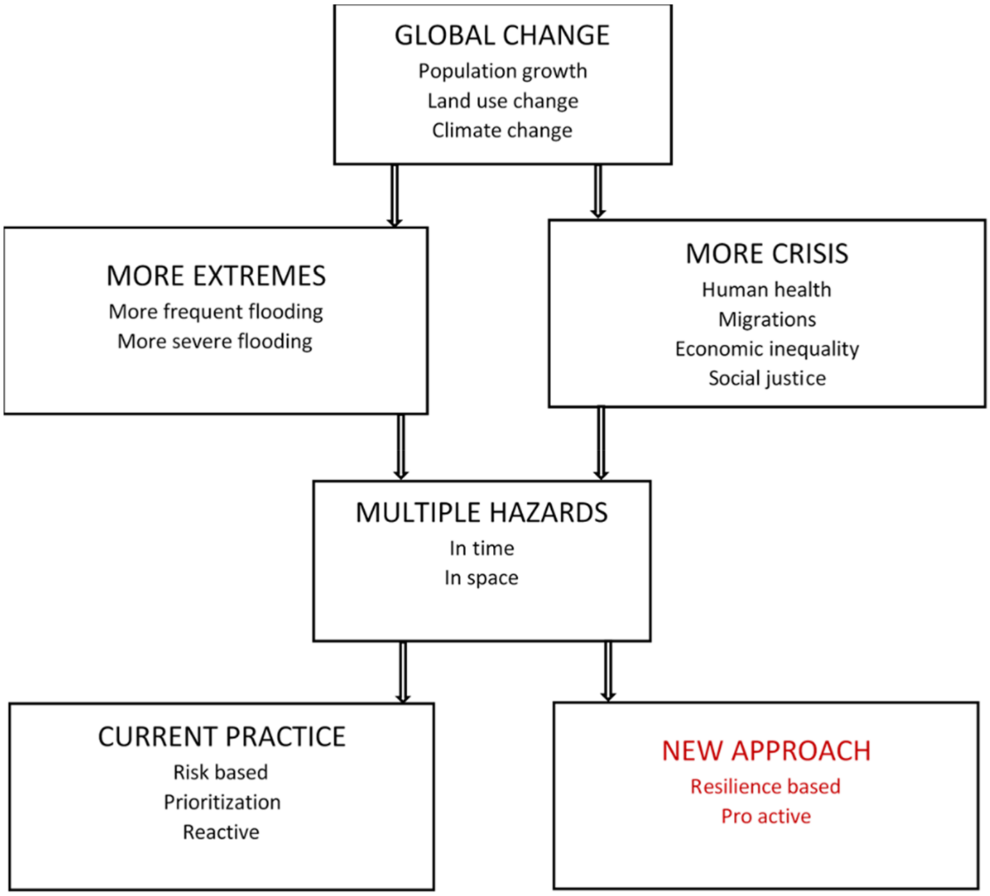


FIGURE 6 Generic presentation of the approach to multihazard management as it can be applied to flooding under the pandemic conditions

adaptation measures. It is worth noting that practice is often ahead of research in this regard, as pointed out by Latour (1999), "… it might be about time for social and natural scientists to forget what separates them and start looking jointly at those 'things' whose hybrid nature has, for many decades now, already unified in practice …."

6 | CONCLUDING REMARKS

Globally changing conditions, including rapid population growth and migrations, climatic variability and change, and land-use change (especially rapid urbanization), are directly affecting the complexity and uncertainty of current and future disaster management problems. Hydrological extremes (floods and droughts) are projected to be more frequent and of higher magnitude in much of the globe. Both, the complexity and the uncertainty, are the result of dynamic interactions within three systems: (a) the physical environment; (b) the social environment; and (c) the constructed infrastructure environment. Within such a complex environment appearance of multiple hazards (at the same time or following each other) is becoming increasingly likely. Social, health and economic conditions under global change can generate various crisis situations, including those such as COVID-19. Figure 6 summarizes the main point of our discussion by providing a generic structure of multihazard management context based on resilience.

Future multihazard crises will be characterized by temporal and spatial dynamics. They will occur at the same moment in time, one immediately after another, or one after another with some time in between. In space, they may occur at fully overlapping boundaries, partially overlapping, or not overlapping at all. These characteristics of multiple hazards represent one of the main challenges in their management.

Current practice in managing multiple hazards is mostly reactive and focused on one hazard at a time. In this approach, priorities are established based on the risk to human life and the first attention is given to hazard with highest immediate potential impact. Risk, (a) being a static measure (independent of time), (b) exhibiting difficulties in assessing the probability distribution of hazard, and (c) being unable to simultaneously consider physical, social, environmental, and economic consequences of hazardous situations, may not be the sufficient tool for addressing challenges of multihazard management (Simonovic, 2016). Many examples of the shortcomings of this approach warrant a focus on investigating other possible management options.

A new approach is needed in dealing with multiple hazards. It should include consideration of the whole region being affected, explicit incorporation of all costs and benefits, development of many alternative solutions, and the active (early) involvement of all stakeholders in the decision-making. Systems approaches based on simulation, optimization, and multiobjective analyses, in deterministic, stochastic, and fuzzy forms, have demonstrated in the last half of 20th century, a great success in supporting effective management of disasters (Simonovic, 2011) and has equal potential for managing multihazard events. To paraphrase Alexander (2020), the planning scenarios for viral pandemics combined with flooding are complex but fully capable of being formulated using a systems approach under uncertainty. Experience with COVID-19 has enabled us to update knowledge of the effects of previous pandemics on modern society at all scales. If uncertainties cannot be eliminated, or reduced, they can at least be clearly communicated in order to provide the firmest possible basis for decision-making.

An unprecedented situation of a compound impact of COVID-19 pandemic and a weather extreme (flood) to health and socioeconomy triggered considerable social and political disturbance throughout the World. Economies affected, unemployment, bankruptcies, major blow to markets and sectors (tourism, therein hotels and restaurants; transport and air transport in particular; sports and recreation; education; culture—theaters, concerts, cinemas; contact jobs—hairdressers, massage; spiritual life—churches, synagogues, mosques, and temples); for fear of infection or dramatic reduction of demand.

Where threats or hazards are known, emergency management plans should be based on scenarios of what is likely to happen. A scenario is a means of investigating a range of possible future outcomes and basic input into quantitative resilience assessment process (Simonovic, 2016). It enables us to foresee the requirements and investigate options to meet them, rather than relying on inefficient forms of ad hoc last-minute improvisation. As pointed above, the systems approach combined with dynamic resilience as a decision-making criterion can provide effective support for multihazard management.

A multihazard emergency management plan is only as good as its implementation (Alexander, 2020). In the event of a pandemic combined with flooding, the uncertainty in the behavior of the disease and the physical characteristics of the flood event means that plans must be flexible to start with and then adapted to circumstances as these evolve. This underlines the role of dynamic resilience as a support for planning and real time disaster management as a process rather than an end.

The proposed quantitative resilience application is implemented through (a) the development of a detailed simulation model of a system; (b) selection of various adaptation options; and (c) comparison of adaptation options using quantitative resilience as a decision-making criterion. The simulation model describes the region subject to change. The region is described using physical and socioeconomic elements and their interactions (e.g., area under inundation, population affected, health and other critical infrastructure, etc.). The changing conditions include flooding (with its timing, magnitude and spatial extent) and COVID-19 characteristics (e.g., number of people affected, infected, hospitalized, their location in the floodplain, etc.). The simulation process provides outputs in the form of system response to changing conditions. They are then used to calculate the resilience of the system (as discussed in Section 5) without any adaptation measures being considered—base case, and various adaptation measures being tested (e.g., addition of the hospital capacity, additional flood evacuation space, distribution of available resources between flood management and pandemic management, etc.). Calculated resilience for the base case can then be easily compared to other resilience values corresponding to the choice of adaptation measures. These values can serve the decision-making process and assist the response activities. The proposed measure and implementation procedure are tested in a single hazard context of municipal flooding (Irwin, Schardong, Simonovic, & Nirupama, 2016). The web-based decision-making tool is developed and available at http://resilsim-uwo.ca (last accessed November 1, 2020). Similar test has been conducted for a multihazard case of combined wind and water disaster (Schardong, Simonovic, & Tong, 2019). The web-based tool has been developed for this application and is available at http://www.resilsimt-uwo.ca (last accessed November 1, 2020).

The application of the proposed approach is possible in the planning context (before the disaster strikes) for solving various planning problems, selecting proactive measures that can affect system redundancy, increase system robustness, and enhance system resilience. However, the approach can be also used in real time disaster response where different reactive measures that can affect resourcefulness and rapidity can be tested through their impact on system resilience.

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AUTHOR CONTRIBUTIONS

Slobodan Simonovic: Conceptualization; methodology; resources; writing-original draft; writing-review and editing. **Zbigniew Kundzewicz:** Conceptualization; formal analysis; resources; writing-original draft; writing-review and editing. **Nigel Wright:** Conceptualization; methodology; writing-original draft; writing-review and editing.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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