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A Broad Survey on Expected Depth of Flood Inundation at Designated Hospitals for Infectious Diseases in Japan Using Flood Hazard Maps

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Synopsis

This paper reports the results of a broad survey on expected depth of inundation by large-scale floods at designated hospitals for infectious diseases in Japan based on open flood hazard maps. The results showed that inundation was expected at approximately a quarter of all target hospitals by floods of the designed level for river planning, while it was expected at about one-third of them by floods of the probable maximum level. Flood inundation deeper than 10 meters was expected at some hospitals, where self-protection measures such as evacuation to the upper stories or installation of the emergency power system to the upper level may no longer be effective. Close coordination with river management, crisis management and public health authorities is therefore considered to be important for those hospitals to enlarge their capability of crisis management under a complex disaster that consists of the epidemic of severe infectious diseases and large-scale floods.

Keywords: flood inundation, hospital, infectious disease, hazard map, complex disaster, flood response

1. Introduction

Epidemic of novel infectious disease due to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) emerged in Wuhan in December 2019 (Zhou et al., 2020), and subsequently became global pandemic in 2020. This disease has been named as coronavirus disease 2019 (COVID-19) by the World Health Organization (WHO), and seriously impacted not only human lives but also social and economic activities across the world. This novel infectious disease became epidemic and severely decreases social and economic activities also in Japan, where various countermeasures including declaration of the state of emergency by the government have been taken to prevent from overshooting the limit of medical system.

In order to cope with the outbreak of these severe infectious diseases, more than 350 medical institutions have been designated by the national or prefectural governments in Japan to preferentially (or exclusively in some cases) provide medical care for patients with the specific infectious diseases. These designated institutions for specific infectious disease (DISIDs) are expected to play an essential role in the national and regional medical care systems against severe infectious diseases in Japan. The COVID-19 has also been designated as a specific infectious disease under the Act on Prevention of Infectious Diseases and Medical Care for Patients Suffering Infectious Diseases, and DISIDs have provided a great effort to deliver medical care for a number of patients with COVID-19, paying considerable attention to prevent in-hospital infection by the novel coronavirus that has not yet been fully understood.

On the other hand, large-scale floods have occurred repeatedly in Japan in recent years. Japan has been suffered from severe floods almost every year especially since 2015, starting from floods in the Kinu River in 2015, followed by floods due to typhoon hits in Hokkaido in 2016, those in the northern Kyushu in 2017, those in the western Japan in 2018, those due to Typhoon Hagibis in the eastern Japan in 2019, and those in Kyushu Island in 2020. Some of these floods exceeded the designed level for river planning, where flood inundation may not be prevented only by structural measures.

Flood responses, such as evacuation, flood fighting, rescue efforts, relief or quick recovery after inundation, therefore become more important in such large-scale flood events. Flood response is, however, a very complex process which must be completed from decision making to action in a short time from when flood occurrence is predicted till when or just after floods occur. This process can become more complicated and difficult to carry out because of countermeasures against infectious diseases when floods occur while severe infectious diseases are epidemic. In fact, various impacts of novel coronavirus epidemic on flood response activities have been seen in the cyclone disasters in 2020 (WMO, 2020; UNOCHA, 2020; NAWG Bangladesh, 2020). Relief activities after floods in Kuma River and Chikugo River basins in July 2020 also delayed due to various constraints imposed by prevention measures against COVID-19 (e.g., JVOAD, 2020).

Flood responses by DISIDs can become further complicated if those institutions are deeply inundated, because evacuation of patients with infectious diseases requires considerable care as well as human and medical resources (such as ventilators for severely ill patients with COVID-19). Evacuation of those patients can take longer time than usual, or can even be difficult to find the place to evacuate due to constraints in medical and human resources. Suspension of medical services by those hospitals due to flood inundation can also degrade the regional medical level against infectious diseases for a long period time, which may bring crisis in public health depending on the situation of epidemic of severe infectious diseases.

In order to investigate the potential risk of flood inundation at important hospitals for public health, this paper aims at reporting the results of a broad survey on expected flood inundation at DISIDs in Japan by using open flood hazard maps so as to mitigate the impact of complex disasters that consists of large-scale floods and severe infectious diseases.

2. Outline of Survey

2.1 Target Hospitals

The target hospitals of this survey were those on the list of DISIDs as of April in 2019 provided by Japan Ministry of Health, Labour and Welfare (HLW) (2019). Hospitals designated as DISID in Japan can be classified into three categories depending on target infectious diseases and those who designated. One of them is Specific DISID, which is designated by the Minister of HLW, and provides medical care for patients with specific novel infectious diseases, Type-1 infectious diseases (e.g., plaque, smallpox, Ebola hemorrhagic fever, Lassa hemorrhagic fever), Type-2 infectious diseases (e.g., severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS)), and new types of influenza. There are four hospitals listed as Specific DISIDs nationwide. Another is Type-1 DISID, which is designated by the governor of each prefecture, and provides medical care for patients with Type-1 and Type-2 infectious diseases and new types of influenza. There are 55 hospitals listed as Type-1 DISIDs across Japan. The other is Type-2 DISID. This is also designated by the governor of each prefecture, and delivers medical care for patients with Type-2 infectious diseases and new types of influenza. There are 351 hospitals recognized as Type-2 DISIDs which have medical resources specialized for infectious diseases across the country.

Excluding overlapped institutions designated in more than one type of DISID, a survey was conducted for 372 hospitals, which consist of four Specific DISIDs, 51 Type-1 DISIDs and 315 Type-2 DISIDs, in this study (Table 1).

2.2 Survey Method

The survey was carried out mainly by using Multi-layer Hazard Map Viewer (MHMV), which is an open database of hazard maps of various natural hazards such as floods, landslides, or tsunami available on the Hazard Map Portal

Table 1 Target hospitals of the survey.

Types of DISID	Number of Institutions	Remarks
Specific	4	
Type-1	51	Out of all 53 institutions designated as Type-1 DISIDs excluding two also designated as Specific
Type-2 (specialized for infectious diseases)	315	Out of all 351 institutions designated as Type-2 DISIDs excluding 36 also designated as Specific or Type-1.
Total	372	

(https://disaportal.gsi.go.jp/) of Geospatial Information Authority (GSI), Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan (GSI, 2018). Flood hazard maps are provided by river management authorities (MLIT or prefectures) for each river basin. This viewer allows the public to see flood hazard maps in any areas in Japan in an integrated manner without visiting the web site of each river management authority where individual flood hazard map is published.

Two types of flood hazard maps are usually provided in Japan, and both are available on MHMV. One is hazard maps for designed floods (DFs), with which maximum inundation area and depth estimated in floods of the designed level for river planning (with return period of 50-200 years depending on significance of the river basin) can be identified. The other is hazard maps for probable maximum floods (PMFs), which illustrate maximum inundation area and depth expected in the event of occurrence of PMFs (with return period of approximately 1000 years). Both of them were investigated in this survey. Flood risk maps published by prefectures or municipalities were also referred for Specific and Type-1 DISIDs to gain supplemental information on updates in expected inundation.

2.3 Data Handling in Case Information on Inundation Is Not Available

Because hazard maps for PMFs have been introduced only after the amendment of Flood Control Act in 2015, they are still under preparation by authorities in some river basins. Hazard maps for PMFs are therefore not available in those basins. However, it was assumed in this survey that inundation of at least same area and depth can occur in PMFs if inundation is expected in DFs in a concerned river basin. Otherwise, it was regarded that no inundation is expected to occur in PMFs.

Inundation from small rivers may not be included in flood hazard maps in some areas, because the main target of flood hazard maps is inundation from major river systems (including major tributaries). Therefore, the result of this survey indicates the smallest number of DISIDs where inundation is expected in DFs or PMFs.

3. Results of Survey

Estimated inundation depth at DISIDs were classified into four categories, namely, no inundation, inundation up to 1-meter deep, maximum inundation depth from 2-4 meters, and maximum inundation depth of 5 meters or deeper (Table 2). Results of the survey for the all target DISIDs (372 institutions) are shown in Fig. 1. Inundation was expected at 95 hospitals (25.5% of the target DISIDs) in DFs. Among these hospitals, maximum inundation depth was expected to be 2-4 meters or deeper at 50 hospitals (13.4%), and 5 meters or deeper at 9 hospitals (2.4%). On the other hand, inundation was expected at 125 hospitals, which is 33.6% of the target DISIDs, in PMFs. Among these hospitals, inundation was expected to reach 2-4 meters or deeper in maximum at 99 hospitals (26.6%), and 5 meters or deeper at 33 hospitals (8.9%).

Results of the survey for Specific and Type-1 DISIDs (57 institutions in total), both of which provide medical care for patients with Type-1 infectious diseases, are summarized in Fig. 2. Inundation was expected at 17 hospitals (29.8% of total) in DFs. Among these hospitals where

Table 2 Categories of maximum inundation depth.

Maximum Inundation Depth	Descriptions
5 meters or deeper	The second level of buildings is submerged, and inundation may reach the third floor or higher.
2-4 meters	The first level (lowest level) of buildings is submerged, and inundation can reach the second floor.
1 meter	Inundation can reach above floor level, but do not exceed the height of adults.
No inundation	Including the hospitals where no information on inundation was confirmed.

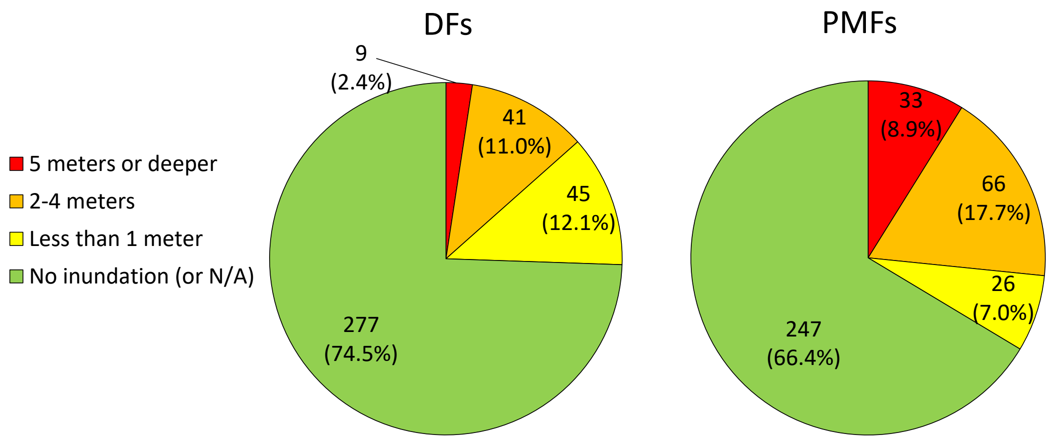

Fig. 1 The number of hospitals in each category of maximum expected inundation depth in designed floods (left) and probable maximum floods (right) for all target DISIDs.

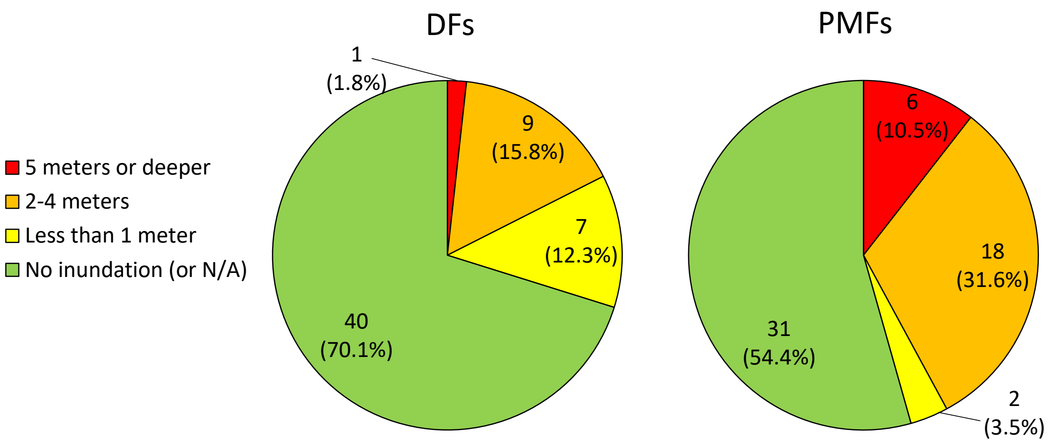

Fig. 2 The number of Specific and Type-1 DISIDs in each category of maximum expected inundation depth in designed floods (left) and probable maximum floods (right).

inundation was expected, maximum inundation was expected to be 2-4 meters or deeper at 10 hospitals (17.5%), and 5 meters or deeper at one institution (1.8%). On the other hand, 26 hospitals (45.6%) were expected to be inundated in PDFs. Among these hospitals, expected maximum inundation depth was less than 1 meter only at 2 hospitals (3.5%), while it was from 2-4 meters or deeper in the other 24 hospitals (42.1%). Expected inundation depth was 5 meters or deeper at 6 hospitals (10.5%),

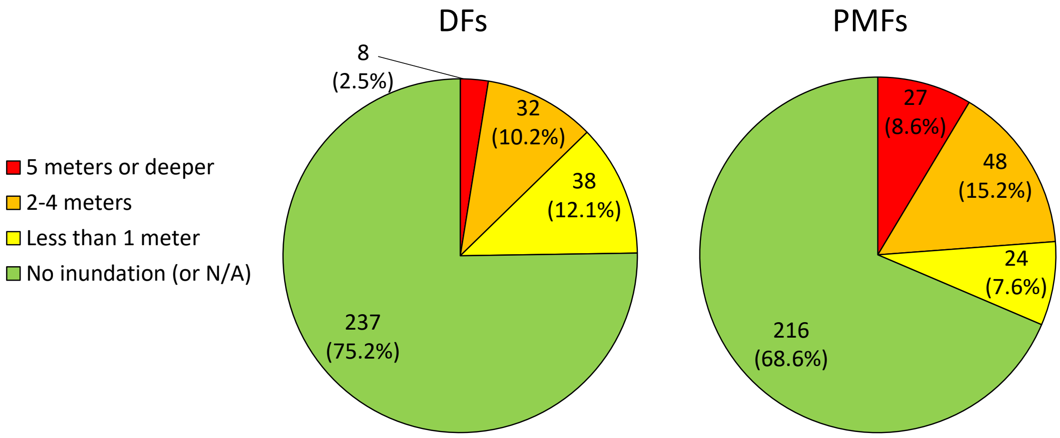

Fig. 3 The number of Type-2 DISIDs (with medical resources for infectious diseases) in each category of maximum expected inundation depth in designed floods (left) and probable maximum floods (right).

and even deeper than 10 meters in some institutions.

Lastly, results of survey for Type-2 DISIDs with medical resources for infectious diseases (315 institutions) are shown in Fig. 3. Inundation was expected at 78 hospitals (24.7% of all target Type-2 DISIDs) in DFs. Among these hospitals, inundation depth was expected to be 2-4 meters or deeper in maximum in 40 hospitals (12.7%), and 5 meters or deeper in maximum in 8 hospitals (2.5%). On the other hand, 99 hospitals (31.4%) were expected to be inundated in PMFs. Among these hospitals, inundation depth was expected to be 2-4 meters in maximum in 75 hospitals (23.8%). Maximum inundation depth was expected to be 5 meters or deeper in 27 hospitals (8.6%), and even deeper than 10 meters in some hospitals.

4. Result Summary and Discussions

Among 372 DISIDs investigated in this survey, 95 hospitals, which are approximately a quarter of all target hospitals, were expected to be inundated in DFs. When Specific and Type-1 DISIDs are focused, 17 (equivalent to one-third) out of 57 target hospitals were expected to be inundated in DFs for the river basins where they are located. On the other hand, 125 hospitals, which are equivalent to one-third of all target DISIDs, were expected to be inundated in PMFs. Especially, nearly half of the Specific and Type-1 DISIDs were expected to be inundated in PMFs. For those which are expected to be inundated up to 1-meter deep among these hospitals, it can be considered to be an effective measure to prevent water intrusion into the building, such as installation of water stops or sandbags.

On the other hand, expected maximum inundation depth was 2-4 meters or deeper at 50 hospitals, which is equivalent to 13% of all target DISIDs, in DFs. The number of hospitals expected to be inundated to this depth increased to 99 (27% of total) for PMFs. Furthermore, the percentage of hospitals expected to be inundated to this depth further increased to 42.1% (24 out of 57 hospitals) when only Specific and Type-1 DISIDs are considered. This indicates that potential floods pose a serious risk to medical system against Type-1 infectious disease, which is usually very serious considering their high fatality rates, when PDFs are considered.

As shown in Table 2, the first floor of the building can totally be submerged and inundation can reach the second floor when inundation depth is 2-4 meters. In this case, it is difficult to prevent water intrusion into the building by installation of water stops or sandbags. Therefore, measures need to be taken on the premise of inundation of the building. Especially in case that it is considered difficult to evacuate patients with infectious diseases and medical resources, beds and medical resources for those patients need to be placed on higher levels in no danger of submergence from the

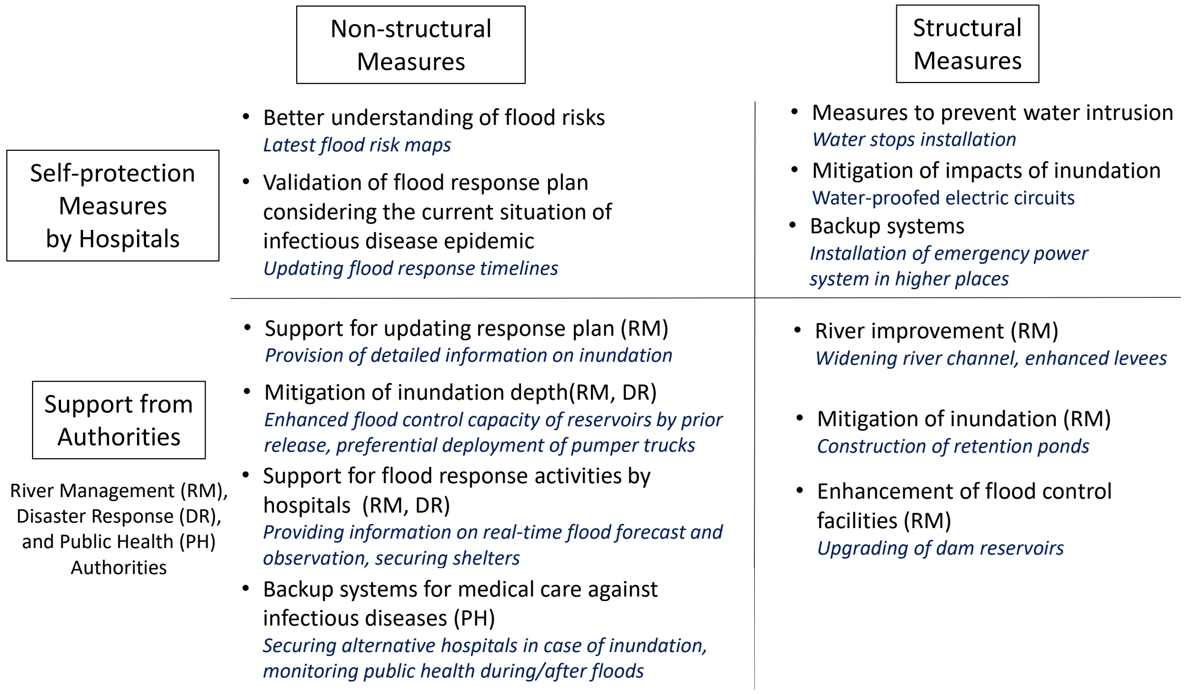

Fig. 4 Relationships among measures to be taken by relevant players for improved flood response by DISIDs (hospitals) under the epidemic of severe infectious diseases.

beginning. It is also desirable for these hospitals to have waterproof electric circuits, or to install emergency power system in higher places, so as to maintain minimal electrical power to provide medical care for critical patients even if their buildings are submerged by flood inundation. At the same time, installation of water stops or sandbags is still considered to be effective for these hospitals in the event of inundation lower than expected, which can happen more frequently.

Maximum inundation depth was expected to be 5 meters or deeper at 9 hospitals of all target DISIDs in DFs. On the other hand, inundation depth for PMFs was expected to be 5 meters or deeper in maximum at 33 hospitals, which are equivalent to 8.9% of all target DISIDs. This rate increased to 10.5% (6 hospitals) when only Specific and Type-1 DISIDs are considered. Countermeasures similar with described above can be considered effective for these hospitals, while it must be paid attention that up to the second level of the building can be totally submerged when inundation rises around five meters.

Maximum inundation depth was expected to be above 10 meters in some of DISIDs in DFs or PMFs. In this case, almost the whole building of hospital might be submerged and damaged by flood inundation, if it does not have higher stories. This can lead to severe degradation of regional medical system against infectious diseases during and after the flood event. In order to mitigate the impacts of inundation at these DISIDs, depth of inundation has to be decreased. This cannot be accomplished only by self-protection measures against floods by hospitals.

Supports from other players such as authorities of river management, disaster response and public health are therefore crucial for successful flood management for these hospitals. For example, river management authorities or reservoir managers can contribute to the mitigation of inundation depth by operating upstream reservoirs for flood control in more effective manner by use of advanced hydrological predictions such as long-range ensemble forecasts (Nohara et al., 2015; Nohara et al., 2018). On the other hand, authorities of flood response (usually municipalities in Japan) can contribute to reduction in inundation depth by preferentially deploying a flood fighting team or pumper trucks for drainage around hospitals where deep inundation is expected. Flood response authorities can also support these hospitals for designing a feasible plan for their flood response activities from the viewpoint of crisis management. Authorities of public health can arrange shelters or backup institutions for these hospitals in the interest of public health in order to maintain regional medical system against infectious diseases.

Like this way, there are many things which can be done by other players than hospitals themselves for raising flood preparedness level of DISIDs. Close cooperation among them is therefore inevitable to cope with the risk of complex disasters between floods and severe infectious diseases such as COVID-19. Important characteristics of this complex disaster are that authorities for public health also play a crucial role in flood response of medical institutions for patients with severe infectious diseases. It is therefore worth noting that close communication with public health authorities before flood occurrence is needed for DISIDs, river management authorities and flood response authorities to smoothly involve the specialist of public health in regional flood response. Planning flood response timelines of the river basin with the participation of related players and authorities can also be an effective way to establish a close collaboration among them. Fig. 4 depicts the conceptual relationships among measures to be taken by relevant players for improved flood response under the epidemic of severe infectious diseases.

From the long-term point of view, land use management can be an effective way to mitigate flood risks of DISIDs highlighted here by regulating land use for such critical public infrastructure in flood-prone areas. Such a policy for land use would become more and more feasible in the countries like Japan where population is going to rapidly decline in the future.

5. Conclusions

A broad survey on expected depth of inundation by large-scale floods at designated hospitals for infectious diseases in Japan was carried out based on open flood hazard maps. The results showed that inundation was expected at approximately a quarter of target hospitals by DFs, while it was expected at about one-third of them by PMFs. Inundation deeper than 5-10 meters was expected at some hospitals, where self-protection measures by hospitals may no longer be effective. Close coordination with river management, disaster response and public health authorities is therefore considered to be important for those hospitals to enlarge their capability of crisis management under a complex disaster, which consists of the epidemic of severe infectious diseases and large-scale floods.

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