Effectiveness of investing in flood protection in metropolitan areas: Lessons from 2019 Typhoon Hagibis in Japan

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Abstract

Purpose: This study aims to demonstrate the effectiveness of investment in flood protection by analyzing the flood disaster caused by Typhoon Hagibis in Japan in October 2019. The typhoon severely damaged the central and eastern Japan regions and threatened the Greater Tokyo area.

Design/methodology/approach: The paper examines flood risks in the Greater Tokyo area and reviews how the flood protection systems functioned to protect Tokyo from the typhoon. The hydrological data of rainfall and water levels at major rivers and the operation records of flood control facilities are collected and analyzed.

Findings: The study's major finding is that the flood protection system succeeded in protecting the Greater Tokyo area from flooding. Typhoon Hagibis maintained its power until landing because of climate change and caused record-breaking rainfall. In a worst-case scenario, thousands of people could have died and hundreds of billions USD worth of assets could have been lost in Tokyo.

Practical implications: The paper describes the actual effects of the flood protection systems, consisting of dams constructed upstream, reservoirs midstream, and diversion channels downstream. Thus, this study's findings directly relate to practical implications for other countries and cities, which face flood risks under a changing climate.

Originality: The paper highlights the importance of investing in flood protection by examining actual disasters and providing detailed descriptions of flood protection systems.

Keywords: Typhoon Hagibis, Japan, Flood protection, Investment, Climate change, Greater Tokyo area

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1. Introduction

Disaster damage is increasing worldwide due to urbanization, development activities, and climate change (Golnaraghl et al. 2020, Jongman et al. 2014, Ward et al. 2017, Winsemius et al. 2016). In particular, urban areas have been developed in coastal areas and are hence vulnerable to climate change (Aerts et al. 2014, Jha et al. 2012). Abadie et al. (2017) estimate that economic losses due to floods for the 120 cities around the world could range from USD2.5 trillion to US$3 trillion by 2050.

Investing in disaster risk reduction (DRR) is becoming more important to mitigate damage in megacities (Jha and Stanton-Geddes 2013). The Sendai Framework for Disaster Risk Reduction, which UN Member States adopted in 2015 at the Third UN World Conference on Disaster Risk Reduction in Sendai, emphasizes investment as a priority action for decreasing disaster risks and losses (UNISDR 2015). Physical flood protection measures, such as dikes and embankments, are generally cost-effective in urban areas with high population and asset concentrations (Ward et al. 2017).

Demonstrating the effectiveness of an actual investment is crucial for promoting investment in DRR. Most countries spend DRR budgets mainly for disaster response and recovery phases and allocate limited resources to invest in proactive mitigation measures (Gaillard and Mercer 2013, Kawasaki and Rhyner 2018).

This paper aims at examining the effectiveness of investing in flood protection systems in the Greater Tokyo area. Typhoon Hagibis severely damaged the central and eastern Japan regions in October 2019 and threatened the Greater Tokyo area where Japan's socioeconomic and political heartland is located. If the area had suffered from flooding, the damage would have been even greater. The typhoon would have affected industrial, commercial, and financial sectors and industrial production in other countries through supply chains. The paper examines Tokyo's risks and how the flood protection systems have functioned thus far[1].

2. Japan's investment in flood protection

This section reviews the trends and effects of investments in flood protection in Japan. Recent studies have estimated the effectiveness of investment at the national level but do not cover how flood protection systems systematically function to mitigate damage caused by floods, such as the flood disaster caused by Typhoon Hagibis in 2019.

Japan has invested in flood protection for more than a century and has increased its resilience to floods. The country launched the national projects of flood protection with the beginning of modernization in the late 19th century (Ranghieri and Ishiwatari 2014). For example, the government started river

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improvement projects in the Tonegawa River to protect the Tokyo Greater area in 1900 (Takahasi and Okuma 1979). The government introduced modern technology by employing Dutch engineers (Takahasi and Uitto 2004). The government also developed legislation, budgetary systems, long-term plans, and institutions to implement flood protection projects (Ishiwatari and Surjan 2019). The budget of flood protection accounts for 0.5-1.3% of the national income until 1910, before the budgets for military expansion and war were increased. Japan suffered from severe floods following World War II because of limited investment in flood protection during the 1930s and World War II (Takahasi 2009). Annual economic damage caused by the floods ranged from 1 to 10 % of the national income from 1946 until 1959, and over 1,000 people died almost every year during this period (Ishiwatari 2019).

In the aftermath of a series of severe floods, the country began to increase its flood protection budget. The budgets of flood protection and rehabilitation accounted for 53% of the total budget of public works in 1956 and continued at over 40% until 1962. The Japanese government allocated the budget for flood protection at about 1% of the national income, which is more than the economic damage of flooding from the 1960s until the 1990s (Ishiwatari and Sasaki 2020). Tsukahara and Kachi (2016) estimated the annual benefit from flood protection investment at over 6 trillion JPY, or 55 billion USD, in the mid-1990s. This was almost double the budget for flood protection.

Areas protected from floods more than doubled in 2000 as compared to 1960, with the flood protection ratio increasing from 24% in 1960 to 56% in 2000 (MLIT yearly). The flood protection ratio is defined as the ratio of protected areas to risk areas of once-in-30-to 40-year floods for major rivers and once-in-5- to 10- year floods for non-major rivers. The ratio increased by 1.0 to 1.6 % annually in the 1980s and the early 1990s. The government promotes flood protection projects based on different safety levels for each river. It has set the safety levels of major rivers in strategic areas, such as Tokyo and Osaka metropolitan areas, at a once-in-200-year scale of floods and the levels of tributaries and other rivers at lower levels. For example, the tributaries of the Arakawa River's safety level, whose embankments were breached in Saitama Prefecture, adjacent to the Tokyo Metropolitan area in October 2019, are set at a once-in-100-year scale.

Investment in flood protection in urban areas also shows a positive return. The government initiated urban flood protection programs in the 1980s. Increasing flood damage in urban areas has become a severe social issue during high economic growth (Ishiwatari 2016, Mushiake 2012). The Ministry of Land, Infrastructure, and Transport (MLIT 2004) evaluated the benefit-cost ratio of urban flood protection programs at 3.3. The government invested JPY3.7 trillion, around USD34 billion, for 23 years at the 2001 price. The ministry estimates the benefits of flood damage reduction for this period to be JPY12.3 trillion, or USD112 billion.

3. Climate condition and emergency response in October 2019

The sea surface temperature has been rising around Japan, and the Typhoon Hagibis maintained its power until landing by drawing energy from the sea surface. During the typhoon development, the sea surface temperature was over 30°C, which was more than 1°C higher than the normal temperature (JMA 2019a). The temperate in October 2019 was higher than in the same period ten years before (Figure 1). The sea surface temperature near Japan rose by 1.12 ° C over the last 100 years to 2018. This is greater than the 0.52 ° C / 100-year average rise in sea surface temperature across the North Pacific (Japan Meteorological Agency 2019b).

Rain clouds developed by the typhoon and the moist air around it caused record-breaking rainfall in the Kanto and Tohoku regions on October 12 and 13, 2019 (Hoshino 2020, Tay et al. 2020). The total rainfall reached 1,000mm at the Hakone monitoring station in Kanagawa Prefecture and exceeded 500mm at 17 stations throughout the country. Also, 120 of some 1,300 monitoring stations across the country reached a record high of 12-hour rainfall. Embankments were breached at 140 sites in some 80 rivers. Floods occurred at more than 300 sites, and landslides occurred at 962 sites, which is the new record high of landslides occurrences by a typhoon since 1982 (Irasawa et al. 2020). Because of flooding and landslides, 96 people died, and 3 people went missing as of January 10, 2020. More than 60,000 houses were damaged, and around 30,000 houses were inundated (Cabinet Office 2020). Critical infrastructure was also damaged. Thirteen expressways were damaged, and 10 bullet trains were submerged. Thirty-three hospitals, 47 elderly nursing facilities, and 31 facilities for disable people were flooded (MLIT 2020). Shimozono et al. (2020) surveyed the coastal areas and found little damage by storm surges because peak storm surge occurred during low spring tide.

To respond to the disaster, the government established the emergency headquarters of disaster management, and the Prime Minister chaired its first meeting on October 13. Government organizations, ordinary people, and researchers used information and communication technology and SNS for response activities. Susilo et al. (2020) point out that the government organizations provided active information and early alert through such methods and raised people’s awareness about the threat of disaster. Ordinary people could access disaster information with fast and reliable internet service during the disaster. Utsu and Uchida (2020) found that Twitter was widely used by government organizations and the public and was effective for conducting search and rescue operations. A spaceborne synthetic aperture radar was used to detect flooded areas and organize disaster response activities (Natsuki and Nagai 2020). In February 2020, however, the COVID-19 pandemic delayed recovery works since local governments suspended receiving volunteers as a measure to prevent the spread of the virus (Ishiwatari et al. 2020). While these recent studies analyze climate and hydrological situations, damage, response activities, they do not cover how flood protection systems functioned at the time of the disaster.

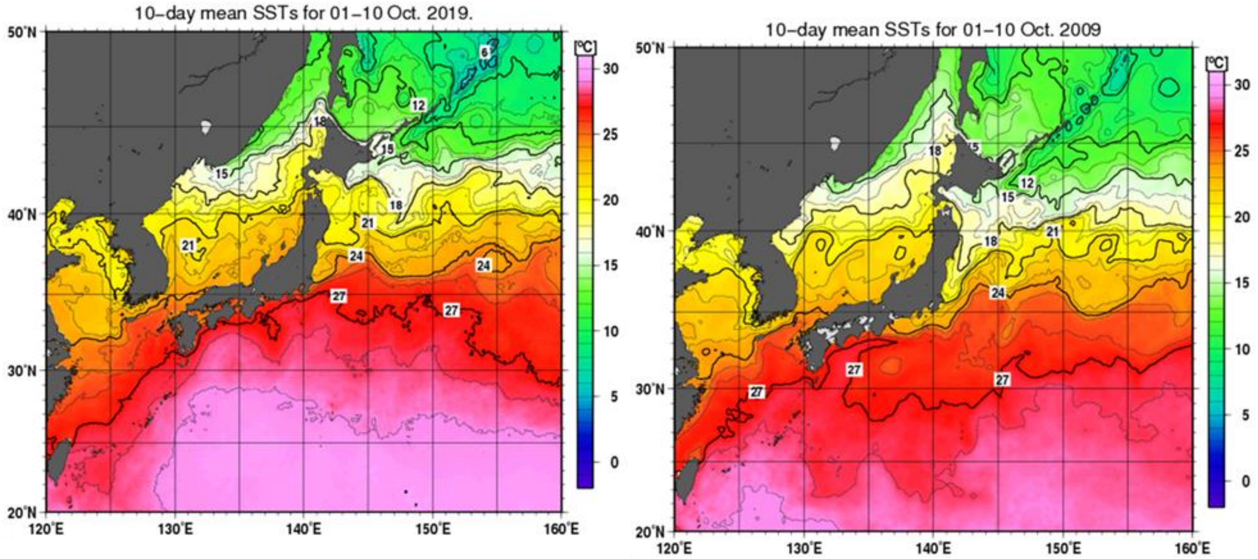

Fig. 1. Sea surface temperature. Left: October 1-10, 2019, Right: October 1-10, 2009

Source: Average sea surface temperature, Japan Meteorological Agency

4. Methodology

The analysis covers three major rivers that flow through the Greater Tokyo area, The Arakawa River runs along the northern districts in the Greater Tokyo area, the Tonegawa River along the eastern districts, and the Tamagawa River along the southwestern districts (Figure 2). Each river is home to millions of people and has accumulated assets of between 0.7 trillion to some 2 trillion US dollars (Table 1).

The following data were collected and analyzed: the hydrological data of rainfall, water levels, and flow volume; damage of flooding; and the operation records of flood control facilities. The post-evaluation reports of government organizations and the papers concerned were also reviewed.

Fig. 2. Major rivers in the Greater Tokyo area

Table 1. Basic information on the major rivers in the Greater Tokyo

River	Population, million	Assets, trillion JPY (trillion USD)	Area of the river basin, km^2	Length of the main channel, km
Tonegawa	13.1	239 (2.2)	16,840	322
Arakawa	10.2	213 (1.9)	2,940	173
Tamagawa	4.1	76 (0.7)	1,240	138

Source: Length of A-Class rivers, MLIT

5. Effectiveness of investment

5.1 Risks Tokyo faced

The Typhoon Hagibis caused heavy rainfalls in the Kanto Region and threatened the Greater Tokyo area. The probabilities of average precipitation were estimated at once every 80 years in the Arakawa River basin and once every 160 years in the Tonegawa River basin (Kanto Regional Development Bureau 2019c).

Flood flow volumes in the three major rivers, Tonegawa, Arakawa, and Tamagawa, exceeded their flood flow capacities in 2019. This resulted in cracks and slides on river embankments, threatening the overflow and breach of embankments, and cause damage to the Greater Tokyo area. On October 12 and 13, five monitoring stations along the major rivers' main channels recorded water levels 9 to 54 centimeters higher than the design high-water levels (Table 2). The government had constructed embankments with free boards, providing additional height over the design high-water levels, to prepare for such unforeseen situations. Because of the free boards and proper maintenance of embankments, floodwater did not breach.

If the major rivers had caused flooding, the damage could have become enormous. In the Tonegawa River basin, a worst-case scenario of a once-in-200-year flood is estimated to cause the death of 2,600 people, economic damage of 34 trillion JPY or 300 billion USD, inundation of 530km^2 areas, and isolation of 1.1 million people (Cabinet Office 2008). In 1947, Typhoon Kathleen caused flood disasters in the Tonegawa River basin, killing 1,000 people, flooding more than 300,000 houses, and damaging more than 30,000 houses (Central Disaster Management Council 2010). In the Arakawa River basin, a worst-case scenario of a once-in-200-year flood is estimated to cause the death of 2,000 people, economic damage of 22 trillion JPY or 200 billion USD, inundation of 110 km^2 areas, isolation of 860,000 people, and the submerging of 147-km-long railway network with 97 stations (Cabinet Office 2008, Japan Society of Civil

Engineers 2018). The Tamagawa River basin has 1.2 million people living in flood risk areas of 9,000 ha and contains assets worth 10.2 trillion JPY or 93 billion USD (Committee of Formulating Basic Concept of Tamagawa River Development 2001).

Table 2. Monitoring stations with recorded water levels higher than the design-high-water levels

River Monitoring station	City Prefecture	Flood peak date and time	Peak floodwater level (WL) (a) (meter)	Design-high WL (b) (meter)	Exceeded height (a)-(b) (meter)
Arakawa River Taroemonhashi	Okegawa Saitama	Oct 13 3:00	15.02	14.93	0.09
Tonegawa River Kawamata	Meiwa Gunma	Oct 13 2:00	8.00	7.46	0.54
Tonegawa River Otashinden	Kamisu Ibaraki	Oct 13 19:00	3.11	2.72	0.39
Tamagawa River Ishihara	Chofu Tokyo	Oct 12 23:00	6.24	5.94	0.30
Tamagawa River Denenchofu	Ota Tokyo	Oct 12 23:00	10.77	10.35	0.42

Source: Water Information System, MLIT

5.2 Flood protection effects

The flood protection system, which the government has developed for over one century, protected the Greater Tokyo area from Typhoon Hagibis in 2019. Damage was limited, mainly inland urban flooding caused by improper drainage operations in small areas. The protection system consists of dams in the upstream, reservoirs midstream, and diversion channels on the ground and underground downstream. While Tokyo was protected from floods, river embankments, whose safety levels are lower than those in the Tokyo areas, were flooded outside the Greater Tokyo area (Das et al. 2020).

Government organizations have maintained these facilities following construction completion and kept them in a good condition to control floods. MLIT, the leading agency of flood protection at the national level, has established local river offices to manage flood protection facilities. The office staff regularly patrol and maintain embankments along rivers at normal times and operate the facilities to mitigate flood damage.

Nevertheless, the flood in the Greater Tokyo area had the potential to drastically change the Japan's history by disrupting the strength and power of the country and deteriorating the standard of living of the people (JSCE 2018). The Tonegawa River may have flooded and caused a similar or higher scale of inundation than in the 1947 flood since the economy has substantially developed with urbanization over the years. Without the dams and reservoirs, the peak volume at the Yatajima monitoring point in the main channel is estimated to be at 16,500 m^3/s, almost equal to the flood volume of 17,000m^3/s caused by the Kathleen Typhoon in 1947 and equal to the design flood volume of the channel. Seven dams in the upstream of the river stored 145million m^3 water and decreased the peak flood volume from 16,500 m^3/s to 12,800 m^3/s and the peak water level by 1 meter at the Yatajima monitoring point (Kanto Regional Development Bureau 2019a). The Watarase reservoir stored 160 million m^3 of floodwater in the midstream, and the other three reservoirs stored 90 million m^3. Downstream, the outer-metropolitan diversion channel with a 10-meter diameter, which was constructed some 50 meters underground, reserved 12 million m^3 and protected urbanized areas (Kanto Regional Development Bureau 2020b). The channel was completed in 2006 at a cost of 230 billion JPY, or 2.1 billion USD, and mitigated 122 billion JPY worth damage until 2019 (Kanto Regional Development Bureau 2012, Mainichi Shinbun 2019). The government is planning to invest 521 billion JPY, or 4.7 billion USD, further until 2042 in flood protection projects with the safety level of once-in-70-80-year flood. The government estimates its benefit-cost ratio (BCR) at 20.1 by assuming future floods with probability analysis and hydrological simulation (Kanto Regional Development Bureau 2017b).

In the Arakawa river basin, dams, reservoirs, and diversion channels systematically protected Tokyo. Upstream dams stored 45 million m^3, and the Arakawa reservoir stored 35 million m^3 midstream (Kanto Regional Development Bureau 2020b). Downstream, floodwater was diverted from Sumidagawa River, which flows in Tokyo downtown districts, to an artificial diversion channel with 22-kilometer length. Since the diversion channel's floodwater level was higher than that of the embankment of the Suimidagawa River, the Tokyo downtown districts would have been flooded without the diversion channel. Channel construction needed 20 years and was completed in 1930 at a cost of 230 billion JPY, or 2.1 billion USD at the 2010 price. The government is planning to invest 356 billion JPY, or 3.2 billion USD, until 2046 to prepare for the same scale of floods as the 1947 flood, which was the largest one in the post-war era and estimates BCR at 30.4 (Kanto Regional Development Bureau 2016).

Tamagawa River was flowing at the peak flood volume of 6,000 m^3/s over its capacity without causing floods in Tokyo (Keihin River Office 2019). This peak flood volume was 1,400 m^3 more than the design flood volume of 4,600 m^3/s at the Denenchofu monitoring station (Committee of Formulating Basic Concept of Tamagawa River Development 2001). The government invested 169 billion JPY, or 1.5 billion USD, in flood protection projects from 2005 until 2017 and is planning to invest 50 billion JPY, or 450 million USD, until 2030 to prepare for a possible largest flood in the postwar era, estimating BCR at 20.2 (Kanto Regional Development Bureau 2017a).

6. Conclusion

Since flood protection facilities are developed to prepare for infrequent events, such as a once-in-decades flood, people cannot easily understand their effects on a day-to-day basis, unlike other infrastructure. The case of Japan demonstrates that investments in flood protection contribute to protecting socio-economic and political activities in strategic areas with a high concentration of assets and a high degree of land use.

Damage by Typhoon Hagibis in October 2019 would have been far greater without infrastructure developed over the past century. Flood volumes exceeded the flow capacities in major rivers flowing through the Greater Tokyo area. Because river water levels exceeded the design high-water levels on the three major rivers, the embankments could have been breached, leading to flooding in the Greater Tokyo area. In a worst-case scenario, thousands of people would have died and hundreds of billions USD worth of assets would have been lost. Developing infrastructure for flood protection is an effective investment to mitigate flood damage in urban areas and proper maintenance of such facilities helps control floods.

While the cost-benefit analysis is widely used to evaluate flood protection projects based on probability analysis, methodologies for estimating actual benefits of mitigating disaster damage for past investment has not been developed. Further research works should study the methodologies of estimating such benefits of past investments. Japan has invested in flood protection in small river basin and landslide protection in addition to metropolitan areas; future research should focus on examining the effectiveness of these facilities.

The Japanese government predicts that because of climate change, rainfall will increase by 1.1 times, flood discharge by 1.2 times, and frequency of floods by 2 times in the country (Technical committee of flood management plan considering climate change 2019). The country needs to continue investing in flood protection and promote other measures, such as land-use planning and evacuation to adapt to increasing flood disasters under a changing climate.

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