論文　**Original Paper**

A study of flood evacuation plans assuming infectious diseases epidemic such as COVID-19 —Regarding the use of public transportation and the placement of flood evacuation shelters—

Ken-ichi Tashiro*1 and Takao Hashimoto*2

Abstract: We analyzed the flood evacuation plan from the Tama River inundation assumption areas (flood-risk areas) in the Tamagawa and Kinuta districts of Setagaya Ward, Tokyo, in the event of a typhoon. We found that, since the number of evacuees could be as high as 30,000, the use of public transportation is essential. However, the current location distribution of flood evacuation shelters throughout the Ward does not take use of public transportation into consideration; thus, this distribution needs to be reexamined. In particular, the flood evacuation shelters in the Kinuta district need to be reviewed due to an imbalance regarding their placements. In order to encourage the elderly, as well other groups who are required to evacuate first, it is necessary to prepare a group of evacuation shelters that are easily accessi-ble on foot or by public transportation. In the Tamagawa district, on the downstream side, it is possible to use rail transport, such as the Oimachi line, which runs along the north side of the district; how-ever, there are no railway lines in the Tama River flood-risk areas of the Kinuta district, which means that public transportation is insufficient, because only buses can be used.

Key words: Evacuation shelter placement plan considering public transportation; evacuation plans assuming infectious diseases epidemic such as COVID-19; estimated capacity of evacua-tion shelters considering common areas; early issuance of evacuation information

1. Introduction

At the time of writing, the fifth wave of COVID-19 in Japan seems to be subsiding. However, considering that after the third wave subsided, the epidemic continued with the fourth wave, which was affected by the Alpha, Beta, and Gamma variants, and the fifth wave, which was affected by the Delta variant, the future status of the pandemic is completely unpredictable. Since it is possible that an epidemic due to an unknown infectious disease will occur again in the future, it is necessary evaluate current evacuation plans in order to prepare for future disasters that may occur under such conditions.

*1 Graduate School of Engineering, Kokushikan University, 28-1, Setagaya 4-chome, Setagaya-ku, Tokyo 154-8515, JAPAN., TEL：03-5481-3202, E-Mail Address：s0de001r@kokushikan.ac.jp

*2 Dr. of Engineering, Department of Science and Engineering, School of Science and Engineering, Kokushikan University, 28-1, Setagaya 4-chome, Setagaya-ku, Tokyo 154-8515, JAPAN., TEL：03-5481-3274, E-Mail Address：thashimo@kokushikan.ac.jp

In the current study, we summarize the infection status of COVID-19 globally and in Japan, including virus mutations, vaccination status, and other factors, and give an overview of the infection status in Tokyo as well as the transition of COVID-19 patients staying in their homes.

In addition, after giving an overview of the 2021 version of the flood evacuation plan in Setagaya Ward, Tokyo, we analyzed the evacuation plan in the event of a Tama River flood, including factors such as public transportation and evacuation shelter placement with a view of determining what changes could be made to create a more effective, efficient evacuation plan.

Note that the data on the number of households and population used in this paper are as of January 01, 2020, the COVID-19 infection data are as of August 31, 2021, and all other previously reported data are as of September 15, 2021.

2. World and Japan infection status

(1) World Infection Overview

Figure 1 shows the daily global, continental, and Japanese national rates of newly confirmed COVID-19

cases from January 2020 to August 2021, created using the Our World in Data system (Data explorer) of the Global Change Data Lab [1].

The pandemic wave shown in **Figure 1** is clearly different from typical infectious disease winter epidemics, such as colds caused by the four attenuated Human Coronavirus (HCoV) types and influenza.

The wave of infection varies from continent to continent and is not uniform, but when examining it on a global scale, as shown in **Figure 1**, it is possible to divide the total number of cases of infection into five waves, including the smaller, less distinct waves. Looking at the waves of the current pandemic, the three waves that occurred after October 2020 were larger than the first two waves, and to date, there has been no evidence indicating that the waves will stop.

(2) Overview of infection in Japan

Figure 2 shows the infection status in Japan, created using the same method as that used for **Figure 1**.

In Japan, the occurrence of new cases up to now has been divided into five waves, with the current wave being the fifth.

Looking at the relationship between the mutation of the virus and the pandemic situation in Japan, at the time of the third wave, the spread of the conventional strain in Japan, and the variants came into effect from the fourth wave. Around the fourth wave, the conventional strain was replaced by SARS-CoV-2 variants (WHO label: Alpha, Beta, Gamma), which are highly infectious N501Y mutations, and in the fifth wave, a further replacement by the even more infectious Delta variant occurred. In the fourth wave, the N501Y mutation detection rate reached 90% as of April 13 in the Kansai region (Osaka, Kyoto, Hyogo), and May 13 in the Kanto region (Tokyo, Saitama, Chiba, Kanagawa). [2] In the fifth wave, the Delta variant (with Pango lineage B.1.617.2) had a positive rate of approximately 89% in the screening test on 2021/8/16-8/22, and it exceeded 80% in almost all prefectures in Japan. Recently, it has been estimated that almost 100% of new cases have been the Delta variant. [3]

The SARS-CoV-2 variants are shown in chapter (4).

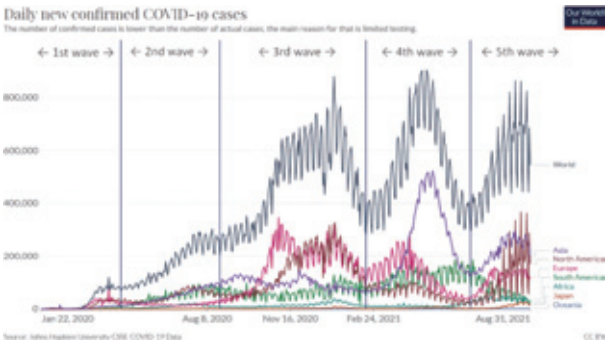

Figure 1. The daily global, continental, and Japanese national rates of newly confirmed COVID-19 cases [1]

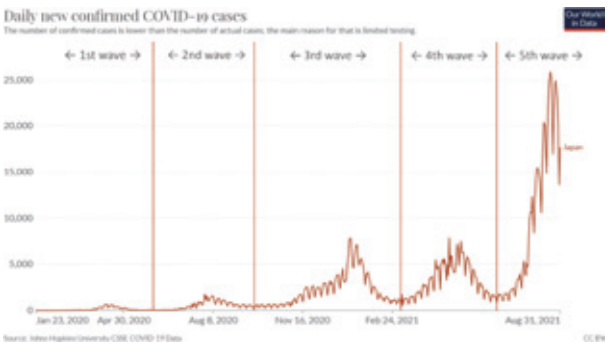

Figure 2. Infection status of COVID-19 in Japan [1]

(3) Similarities regarding the five peaks of the waves of infection between the world and Japan

Figure 3 shows the peaks of the Japanese pandemic waves in relation to the global pandemic, created using the same method as that used for **Figures 1** and **2**. [1]

If we look at the global pandemic wave as five waves, even though the infection rates by continent are not uniform, the peaks of the waves in Japan seem to be similar to those on the global scale.

(4) SARS-CoV-2 variants

The World Health Organization (WHO) has designated variants that posed an increased risk to global public health as variants of concern (VOCs) and / or variants of interest (VOIs). [4]

Tables 1 and **2** are official lists of VOCs and VOIs, respectively, published by WHO.

(5) Coronavirus (COVID-19) Vaccinations

Approximately 40.1% of the global population has

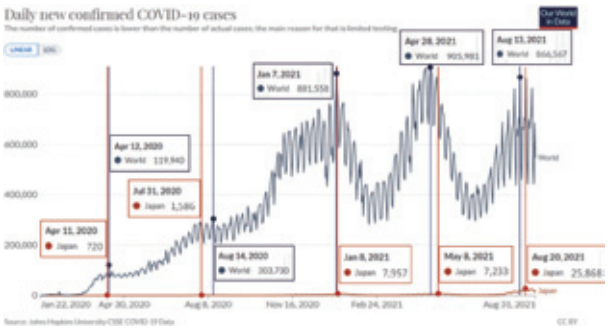

Figure 3. The five peaks of the Japanese pandemic waves in relation to the global pandemic [1]

received at least one dose of a COVID-19 vaccine; 5.41 billion doses have been administered globally, with 38.92 million doses currently being administered each day. [5]

Figure 4 shows the COVID-19 vaccination statuses (COVID-19 vaccine doses administered per 100 people) on global, continental, and Japanese national scales. The figure was created using the Our World in Data system (Coronavirus (COVID-19) Vaccinations) by the Global Change Data Lab. [5]

The vaccinations seem to be proceeding smoothly everywhere except in Africa, but as far as the infection rates in **Figure 1** are concerned, it cannot be definitively determined that the vaccinations have been fully effective in reducing infection rates, because the immune antibodies used decrease over time.

Table 1. List of VOCs published by WHO [4]

Currently designated Variants of Concern:

WHO label	Pango lineage*	GISAID clade	Nextstrain clade	Additional amino acid changes monitored†	Earliest documented samples	Date of designation
Alpha	B.1.1.7 *	GRY	20I (V1)	+S:484K +S:452R	United Kingdom, Sep-2020	18-Dec-2020
Beta	B.1.351	GH/501Y.V2	20H (V2)	+S:L18F	South Africa, May-2020	18-Dec-2020
Gamma	P.1	GR/501Y.V3	20J (V3)	+S:681H	Brazil, Nov-2020	11-Jan-2021
Delta	B.1.617.2‖	G/478K.V1	21A	+S:417N	India, Oct-2020	VOI: 4-Apr-2021 VOC: 11-May-2021

Table 2. List of VOIs published by WHO [4]

Currently designated Variants of Interest:

WHO label	Pango lineage*	GISAID clade	Nextstrain clade	Earliest documented samples	Date of designation
Eta	B.1.525	G/484K.V3	21D	Multiple countries, Dec-2020	17-Mar-2021
Iota	B.1.526	GH/253G.V1	21F	United States of America, Nov-2020	24-Mar-2021
Kappa	B.1.617.1	G/452R.V3	21B	India, Oct-2020	4-Apr-2021
Lambda	C.37	GR/452Q.V1	21G	Peru, Dec-2020	14-Jun-2021
Mu	B.1.621	GH	21H	Colombia, Jan-2021	30-Aug-2021

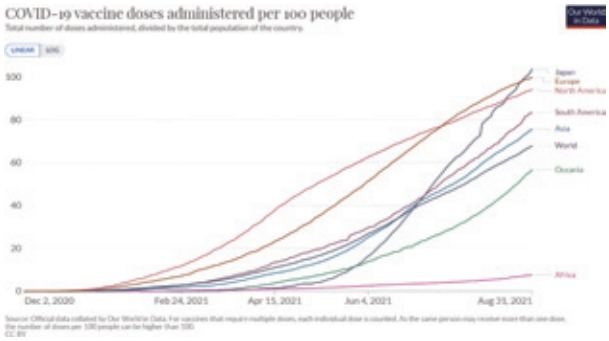

Figure 4. Global, continental, and Japanese national COVID-19 vaccination statuses [5]

(6) Infection status in Tokyo

Figure 5 is a graph of the daily infection rates of COVID-19 in Tokyo according to data supplied by NHK on their website showing new coronavirus cases. [6]

In addition, for the analysis described below, using the data from the Tokyo Metropolitan Government's COVID-19 countermeasure site, the number of COVID-19 patients who are receiving treatment at home (**Fig. 6**) and the number of COVID-19 patients who are waiting at home for a hospital or hotel bed to become available until the coordination by the Public Health Center is completed (COVID-19 patients waiting for a bed to become available) (**Fig. 7**) are shown

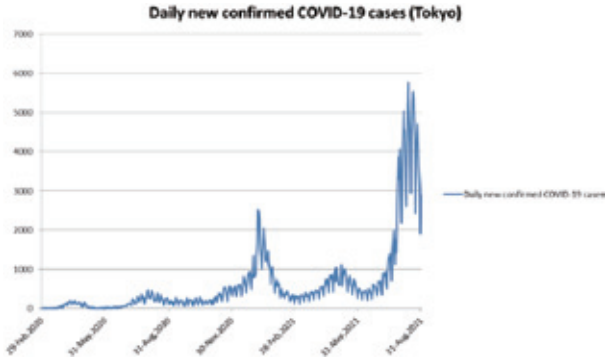

Figure 5. Infection status of COVID-19 in Tokyo [6]

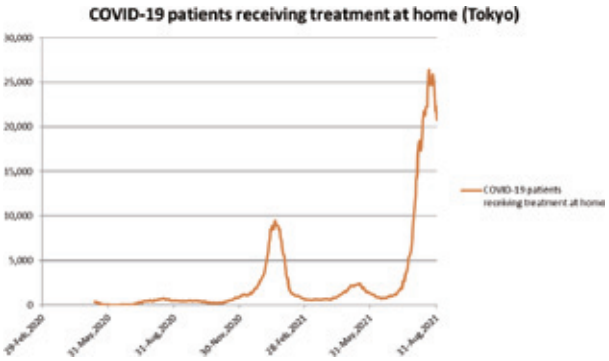

Figure 6. The number of COVID-19 patients who are receiving treatment at home in Tokyo [7]

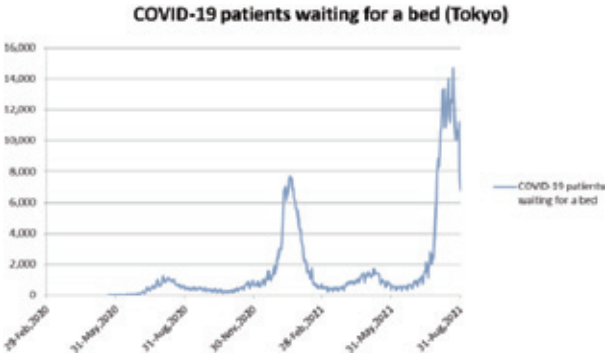

Figure 7. The number of COVID-19 patients waiting for a bed to become available [7]

as graphs.

Figure 8 shows the sum of the patients shown in **Figures 6** and **7**. [7]

3. New flood evacuation shelters in Setagaya Ward

In 2020, Setagaya Ward conducted a comprehensive inspection of storm and flood damage countermeasures regarding the response to the 2019 Reiwa 1 East Japan Typhoon. Based on the results of that inspection, the ward designated shelters to which people can evacuate in the event of a flood (flood evacuation shelters).

(1) A basic concept of how to open flood evacuation shelters

Evacuation information on the Tama River flood "Evacuation of the elderly and disabled. (Alert level 3)" will be issued 24 hours in advance of the typhoon, and flood evacuation shelters will be opened in two stages (a and b below) in order to accept those who evacuate early. [8]

a) Flood Evacuation Shelters (Primary) [8]

In the current plan, in order for the elderly and disabled people living in the Tama River flood-risk areas to get to shelter quickly, elementary and junior high schools and other facilities located far from the flood-risk areas are established as flood evacuation shelters, as quickly as possible.

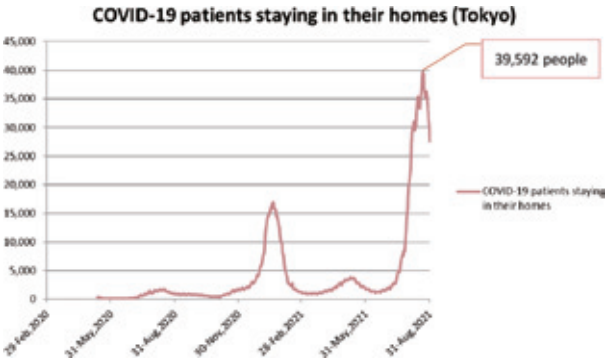

Figure 8. The number of COVID-19 patients staying in their homes [7]

Figure 9. Flood evacuation shelter congestion confirmation system in Setagaya Ward

These shelters have been designated as facilities outside the Tama River flood-risk areas (as shown in **Figure 11**.) because if facilities near the area are opened first as flood evacuation shelters, there will be a much larger number of evacuees arriving later, including those who have been delayed in arriving, for example due to a lack of mode of transportation. These latecomers will lead to confusion and chaos.

The Primary Flood Evacuation Shelters will be opened 24 hours before the approach / passage of the typhoon.

b) Flood Evacuation Shelters (Secondly) [8]

Regarding elementary and junior high schools and other facilities outside the Tama River flood-risk areas in the Tamagawa and Kinuta districts facilities other than those opened as Primary Flood Evacuation Shelters will be opened as Secondary Flood Evacuation Shelters.

In the Setagaya, Kitazawa, and Karasuyama districts, large-scale inundation damage such as the flooding of the Tama River is not expected to occur. Therefore, they will be established as evacuation shelters for some areas at risk of sediment-related disasters, such as the flooding of smaller rivers, or the collapse of houses due to strong winds, and for people who voluntarily evacuate because they do not feel safe due to typhoons and other heavy rain disasters.

c) Flood evacuation shelter congestion confirmation system [9]

From June 1, 2021, the congestion confirmation system for flood shelters started operating. In addition, congestion is divided into four categories; closed, not crowded, crowded, and full.

(2) Extraction of issues in flood evacuation shelters planning

a) Insufficient capacity for flood evacuation shelters in the event of a Tama River flood

The ward has stated that flood evacuation shelters in the Tamagawa and Kinuta districts are sufficient for flood evacuation of the Tama River [10]; however, as shown in the analysis in (1) of the next chapter, taking COVID-19 into account, the estimated capacities of the evacuation shelters would be significantly insufficient.

In addition, the required common areas are not taken into account. When taking these areas into consideration, the capacities of the shelters will inevitably become even smaller. This issue is also discussed in Chapter 4.

b) Placement of the flood evacuation shelters in the Kinuta

district

As shown in (2) of the next chapter, Primary Flood Evacuation Shelters in the Kinuta district are located farther from the Tama River flood-risk areas than those in the Tamagawa district, indicating that accessibility for evacuees who require support was not taken into consideration.

c) Arrangement of evacuation shelters considering public transportation routes

The ward's flood evacuation plan assumes that elderly people and others who require support. will evacuate using public transportation before its planned suspension. [11] [12]

However, this will not work unless the evacuation shelters are arranged in a way that takes public transportation routes into consideration.

d) Measures to evacuate about 30,000 evacuees using public transportation

As shown in (1) a) in the next chapter, the number of evacuees may reach about 30,000 even taking the distributed evacuation rate into account. It is necessary to consider measures to evacuate such people using public transportation.

In order to evacuate 30,000 evacuees, it is necessary to urge not only the elderly, but also the general population to evacuate as soon as possible. During the Reiwa 1 East Japan Typhoon, planned suspension of public transportation was implemented before the evacuation information was issued (**Table 7**). Unless this information is issued to the general public as early as possible, there will be more confusion than during the typhoon, especially under the conditions of an infectious disease epidemic such as COVID-19.

e) Evacuation problem for evacuation persons requiring support

It is necessary to create evacuation plans for all residents in the area who require support, with each plan taking each person's individual needs into consideration.

f) Evacuation problems for COVID-19 patients staying in their homes

In Setagaya Ward, it is necessary to consider an evacuation plan for number of patients who are treated at home, or require hospitalization and medical treatment, but must stay home due to lack of available beds. A plan for such individuals has not yet been formulated. In the current paper, in particular, the transfer plan for patients who are treated at home, or require hospitalization and medical treatment, but must stay home due to lack of available beds will be examined.

4. Analysis of the new Tama River flood evacuation plan in Setagaya Ward

(1) Analysis of flood evacuation shelter capacities in the event of Tama River flooding

a) Estimate of the number of evacuees to evacuation shelters in the event of a Tama River flood

The population of the Tamagawa and Kinuta districts in the Tama River flood-risk areas in Setagaya Ward at the time of analysis (January 1, 2020) was 54,808 (Basic Resident Register). [13][14]

In addition, the evacuation rate to evacuation shelters for Setagaya residents according to the 2020 Attitude Survey of Setagaya Residents was 51.16%, so this will be used for the calculation. [15]

Therefore, the estimated number of people who would evacuate to shelters in the event of a Tama River flood is estimated to be 28,040, as shown in **Table 3**.

b) Estimating the capacity of shelters under the conditions of an infectious disease epidemic such as COVID-19

Case 1: When the common areas of evacuation shelters are included in the calculations of shelter capacity

The Tokyo Metropolitan Government requires the layout of the evacuation space to have makeshift aisles to be 1–2 m wide and the distance between people should be at least 1 m, according to the "Guidelines for Countermeasures against COVID-19 in Evacuation Shelters". [16]

In response to this, the ward also states that "the distance between evacuees (for each family) should be at least 1 m." [17]; however, the formula for calculating the capacity of the evacuation shelters in the Setagaya Ward Local Disaster Management Plan (2 people / 3.3 m^2; 1.65 m^2 / person) has not been updated to reflect this [18].

Since this paper targets short-term evacuation (within 3 days) to avoid difficulties when a typhoon passes, the width of the passage and the distance between evacuees (for each family) have both been determined to be 1 m. However, from now on, due to the influence of SARS-CoV-2 variant strains, it may be necessary to change these distances to 2 m. The number of people per household is approximately 1.88, which was calculated by dividing the population of

Table 3. Estimated number of evacuees to flood evacuation shelters

Population in the target area	54,808 people
Evacuation rate to the shelters	51.16%
Estimated number of evacuees to flood evacuation shelters	
The Tamagawa district	14,063 people
The Kinuta district	13,977 people
Total	28,040 people

Setagaya Ward, 917,486, by the number of households, 487,174, as of the time of analysis (January 1, 2020). [19]

Using the above data, the area occupied by each evacuee under the conditions of an infectious disease epidemic such as COVID-19 is estimated to be 4.60 m^2 / person, as shown in **Figure 10**.

Case 2: When the common areas of evacuation shelters are not included in shelter capacity calculations

Since outdoor spaces cannot be used at evacuation shelters during a typhoon, it is necessary to secure enough indoor space to serve as the required common areas, including a reception space, childcare space, as well as spaces for shoe racks, storing wheelchairs, charging mobile phones, and keeping large fans for ventilation.

Some local government evacuation shelter manuals state that it is necessary to "create a layout diagram in advance and calculate the number of people that can be accommodated"; however, in the evacuation shelter plan of the Local Disaster Management Plan, there are few methods of calculating the number of evacuees based on the surface area of the shelters, excluding common areas.

However, there are some Local Disaster Management Plans that estimate the number of evacuees by not taking common areas into account when calculating shelter capacities; thus, in the current paper, we will deduct the common space and estimate the number of evacuees.
In addition, common spaces aren't included in calculations only in facilities such as gymnasiums. In facilities such as Civic Halls or residents' centers, common areas will be located in alternative places in the same facility, and will not be necessary to exclude from calculations.

Table 4 shows the effective area ratios of local governments who do not include common spaces in capacity calculations. The data in this table do not specify whether the evacuations were short-term or long-term in the Local Disaster Management Plan.

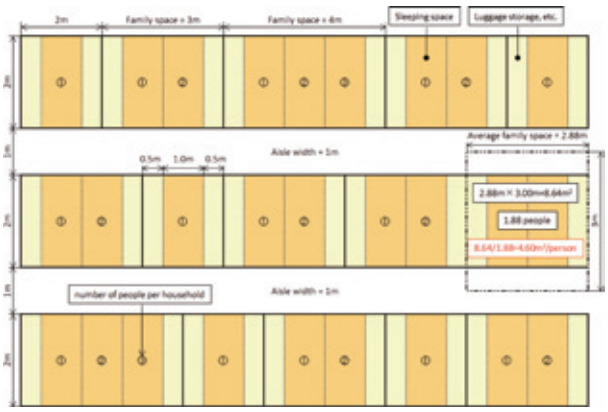

Figure 10. The area occupied by each evacuee under the conditions of an infectious disease epidemic such as COVID-19

In the current paper, short-term evacuation is the focus, and the measures we propose do not include specific sizes of the required common areas into account; thus, separate evacuation plans would have to be made for long-term evacuations. For our proposal, we used the evacuation plans of Hidaka City as our reference.

Table 5 shows the estimated number of people that can be accommodated in flood evacuation shelters in the Tamagawa and Kinuta districts based on the data examined in Cases 1 and 2.

As a result, the current evacuation calculations of Setagaya Ward indicate that the number of evacuees estimated in 4 (1) a) above can be accommodated, but considering the social distance between evacuees and deducting common spaces, it has become clear that, at present, not all evacuees would be accommodated in flood evacuation shelters, should a disaster occur (28,040 people > 9,821 people).

Table 4. Example of the effective area ratios excluding common areas

Local governments	Effective area ratio
Iruma City [20]	66.7% (2/3)
Kashiwa City [21]	70%
Kawagoe City [22]	75%
Soka City [23]	75%
Osaka City [24]	80%
Hidaka City [25]	85%

Table 5. Estimated capacity of flood evacuation shelters in the Tamagawa and Kinuta districts

District	Flood evacuation shelters	Estimated capacity (people)		
		1.65 m^2 / person	4.60 m^2 / person	Case 2
Tamagawa	Primary	7,547	2,705	2,451
	Secondary	10,059	3,605	3,064
	Subtotal	17,606	6,310	5,515
Kinuta	Primary	6,206	2,225	1,898
	Secondary	7,836	2,809	2,408
	Subtotal	14,042	5,034	4,306
Total		31,648	11,344	9,821
Ratio		1.00	0.36	0.31

(2) Arrangement and balance of evacuation shelters in cases of flood, taking public transportation into consideration

a) Arrangement and balance of flood evacuation shelters in the Tamagawa, Kinuta, and Setagaya districts

Figure 11 is a plot of flood shelters in the Tamagawa, Kinuta, and Setagaya districts using the government's "Statistics Map of Japan (jSTAT MAP)" (the same applies hereinafter). [26]

Table 6 shows a common legend of the drawings shown in this chapter.

The Primary Flood Evacuation Shelters in the red frame in the Kinuta district are different from the shelters located relatively near the Tama River flood-risk areas in the blue frame in the Tamagawa district, and are about 2 km or longer in a straight-line from the flood-risk areas (**Fig. 11**). It is clear that this is not a distance that elderly and other vulnerable people can cover on foot when they evacuate.

In addition, while the arrangement of flood evacuation shelters in the Tamagawa district seems to be balanced, the arrangement of the shelters in the Kinuta district cannot be said to be balanced, which makes the arrangement very difficult for the elderly and others. The reason for this is that, as shown in **Figure 11**, the Kinuta district has a long north-to-south shape, and all evacuation shelters near the flood-risk areas are designated as Secondary Flood Evacuation Shelters.

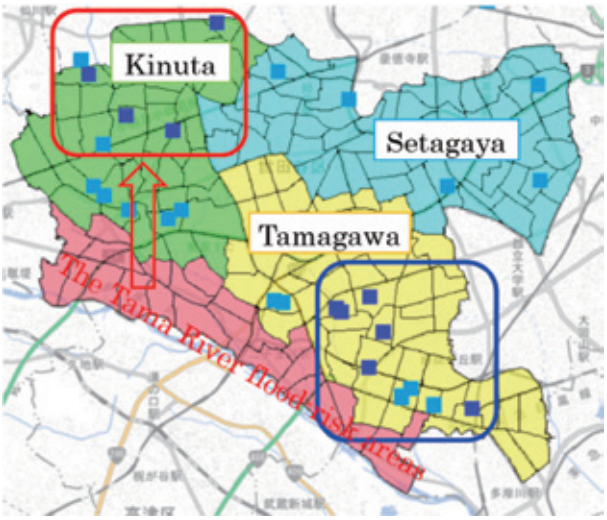

Figure 11. Current locations of evacuation shelters in the Tamagawa, Kinuta, and Setagaya districts

Table 6. jSTAT MAP common legend

CommonLegend	
■	Primary Flood Evacuation Shelter
■	Secondary Flood Evacuation Shelter
■	Designated Emergency Evacuation Shelter
■	Designated Evacuation Shelter
🏛	Other ward-owned facilities
✚	Spare Evacuation Shelter

Even if the Primary Flood Evacuation Shelters were opened 24 hours before the approach of a typhoon, and the order for evacuation of the elderly and other vulnerable people was issued at the same time, in the distant and inconvenient evacuation shelters, many of the people in question would not consider evacuating, leading to a high possibility that they will wait and try to evacuate after the nearby evacuation shelters are opened on the day of the approaching typhoon.

As a result, there is a concern that people may delay their evacuation, and at the same time, the act of opening Primary Flood Evacuation Shelters 24 hours in advance in an attempt to avoid congestion may be meaningless.

Therefore, in the following, we consider a group of shelters that can be reached by traveling using public transportation without changing trains or buses, and, based on the basic idea of opening the Setagaya Ward evacuation shelters in two stages, we believe this strategy would help in reducing confusion and improving both the organization of the evacuation and the comfort of the evacuees.

b) Estimated capacity of shelter groups accessible by public transportation without transfer

We considered a group of shelters that can be evacuated to on foot or by public transportation without changing trains or buses, as the ward plans. [11][12]

Therefore, we investigated the routes that stop at or near evacuation shelters without the need to transfer trains or buses using public transportation from the Tama River flood-risk areas. The results are shown in **Figure 12**.

In addition, although the walking distance to a Primary Flood Evacuation Shelter must be within 500 m according to the Urban Disaster Prevention Practice Handbook [27], the reachable area buffer in **Figure 12** is drawn as a straight-line distance of 500 m from the public transportation line, which is actually slightly longer than 500 m.

According to **Figure 12**, the limits that can be reached from the Tama River flood-risk areas using public transportation without changing trains are the Tamagawa, Kinuta, Setagaya, and Kitazawa districts. However, the northern part of the Kinuta district cannot be reached, and only the southern part of the Kitazawa district can be

reached.

Figure 13 shows the evacuation shelter candidates in the four districts shown in **Figure 12**.

The inside of the red boxes in **Figure 13** are the main evacuation shelter candidates in the Tamagawa, Kinuta, Tamagawa districts, which are within 5 km of the Tama River flood-risk areas, but cannot be reached by public transportation without changing trains or buses.

Table 7 shows the calculated number of people that can be accommodated by the flood evacuation shelters and other evacuation shelters candidates within a straight-line distance of about 500 m from the public transportation routes shown in **Figure 13**.

While the estimated number of evacuees is 28,040, the total estimated capacity calculated in **Table 7** is 27,974, which means that the estimated capacity is still insufficient, by 66 people.

c) Measures to make up for the shortage of shelter capacity

By utilizing partitions and indoor tents, the distance between evacuees can be narrowed, so the estimated capacity of evacuation shelters can be increased even under the conditions of an epidemic of an infectious disease such as COVID-19. However, storage of partitions that are used only when evacuation occurs may hinder the use of the facilities in normal times. In addition, the partitions may take time to assemble, which is not realistic when an emergency evacuation is required in the event of a disaster such as a typhoon. However, if the partitions can be installed even partially, the estimated capacity can be increased.

The ward also takes into consideration that some people may wish to stay in their cars, saying "Evacuees in heavy storms and evacuees accompanied by pets may evacuate by

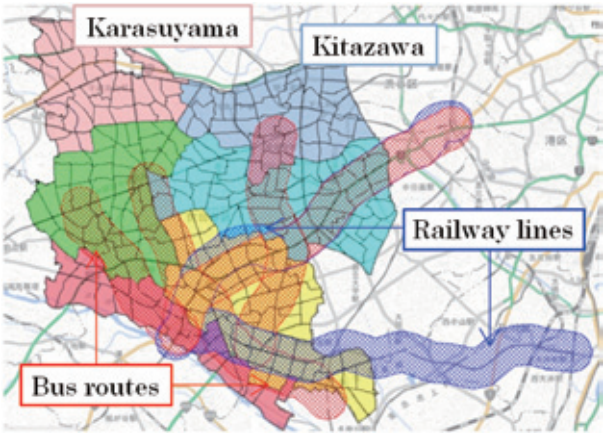

Figure 12. Overlaid view of "Direct transportation routes" from the Tama River assumption inundation area in 5 districts of Setagaya Ward

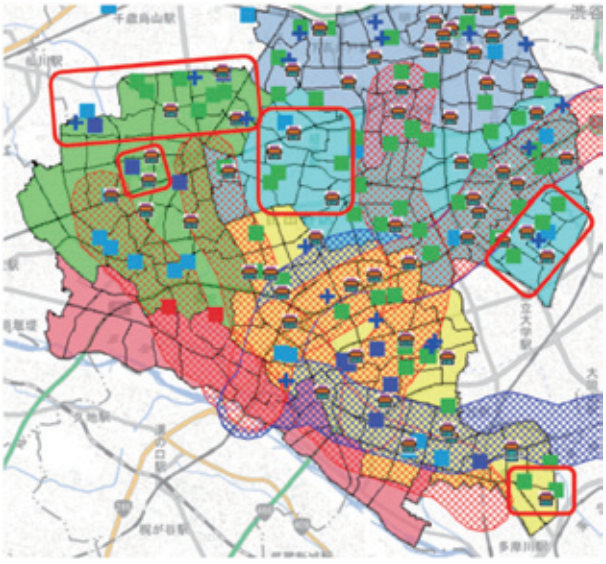

Figure 13. The evacuation shelter candidates in the above four districts shown in Figure 12

Table 7. Estimated capacity of the evacuation shelter candidates

District	Type of shelter	Number of shelters	Capacity (people)
			Case 2
Tamagawa	Flood Shelters	12	5,515
	Evacuation Shelters	11	6,312
	Ward-owned facilities	17	716
	Spare Shelters	6	1,204
	Subtotal	23	13,747
Kinuta	Flood Shelters	7	3,011
	Emergency Shelters	2	273
	Ward-owned facilities	3	307
	Subtotal	9	3,591
Setagaya	Flood Shelters	3	204
	Evacuation Shelters	14	7,638
	Ward-owned facilities	11	606
	Spare Shelters	4	1,207
	Subtotal	17	9,655
Kitazawa	Evacuation Shelters	2	901
	Ward-owned facilities	2	80
	Subtotal	4	981
Total			27,974

car, so it is necessary to consider how to deal with such evacuees." [28]

In addition, the ward states that "the flood evacuation shelters where parking lots can be used will be announced on the website." [28] There are two evacuation shelters available in the Kinuta district, which have parking lots with a combined total of 290 parking spots, and one reserve shelter that has a parking lot with an area of 2,610 m^2. Even assuming that each vehicle contains an average of two people, the disparity between the total number of evacuees (28,040) and the number of evacuees that can be accommodated in the shelters (27,974), a total of 66 people, can be accounted for by taking into account those who will stay in their cars.

The ward plans to make specific adjustments with the facility managers so that metropolitan facilities such as high schools in the Tamagawa and Kinuta districts, as well as private facilities such as universities, can be used as flood evacuation shelters.

If the number of flood evacuation shelters increases, it will be possible to make up for the current shortage of the number of people that can be accommodated.

(3) Transportation capacity issues

Setagaya ward is considering evacuation via public transportation before the planned suspension of transportation operations. In the Tama River flood-risk areas east of Futakotamagawa Station (the Tamagawa district), there is a railway line, the Oimachi Line, that runs along the north side of the district, so transportation capacity would not be an issue. However, the flood-risk areas in the Kinuta district depends on the bus routes because there is no railway lines, so the transportation capacity is insufficient.

The number of people who would evacuate to shelters in the event of Tama River flooding in this areas is estimated to be 13,977, which is about half of 28,040 (**Table 3**).

As for the main bus route of the Kinuta district, the Tamagawa line 07 (from Futakotamagawa station to Seijo Gakuenmae station) has many users, so there are 69 bus trips per day, an average of four trips per hour, and the buses are also large, each with a capacity of 78 people, totaling 312/hour more people who can be transported. In addition to this, the Tamagawa line 31 (Futakotamagawa Station to Seijo-Gakuenmae Station) is also available. On this line are 35 bus trips per day, equaling two trips per hour, in medium-sized buses (capacity 60 people), totaling 120 people who can be transported every hour.

It can be said that these are routes with relatively high transportation density as bus routes, but even if the two routes are combined, the transportation density is only 432 people per hour (one-way transportation volume to Seijo Gakuenmae station, which is the evacuation direction). There are a few other bus routes available; however, the transportation capacity of buses is overwhelmingly inferior to that of railways, which have the capacity of tens of thousands of people per hour. Thus, it is not realistic to transport 13,977 evacuees in a short time.

Therefore, it is clear that in order to transport evacuees from the Tama River flood-risk areas in the Kinuta district, the transportation capacity is insufficient using regularly scheduled buses alone; it is necessary to carry out shuttle transportation using charter buses.

In addition, for evacuation shelters to which evacuees are shuttle-transported on charter buses, for example, if they are transported to evacuation shelters within the red boxes in **Figure 13** that cannot be reached by public transportation without changing trains or buses, congestion at other evacuation shelters would be alleviated.

(4) Evacuation plan for evacuees requiring support

According to data published on Setagaya Ward's website [29], the Tamagawa district has 225 potential evacuees who require support, and the Kinuta district has 280.

Based on the results of a survey of the parties concerned, the ward estimates that the numbers of these people who would evacuate to shelters (and their companions [one per evacuee]) is 122 in the Tamagawa district and 268 in the Kinuta district.

Elderly people aged 65 years and over accounted for about 65% of the fatalities caused by the Reiwa 1 East Japan Typhoon [30], and about 79% of the fatalities caused by heavy rains in July, 2020 [31]. For this reason, in May, 2021, the Basic Act on Disaster Management was amended, and provisions were established in municipalities, such as making efforts to create individual evacuation plans for each person who requires support.

In particular, for those who require evacuation support, it is important for them to have shelters equipped with barrier-free facilities, as well, the other requirements necessary for said support, located in places where they (the evacuees) feel they can access as easily as possible.

For evacuation shelters registered in the individual evacuation plans of evacuees who require support, the persons (and their companions [one per evacuee]) should be given priority. If these evacuees go to Primary Flood Evacuation Shelters, priority spaces should be set up, and at other shelters, even if they are not open to general evacuees, acceptance should start at the same time as the Primary Flood Evacuation Shelters are opened.

(5) Early issuance of evacuation information and establishment of voluntary evacuation shelters

Table 8 summarizes, in chronological order, the response of Setagaya Ward to the Reiwa 1 East Japan Typhoon. It shows that even the announcement of "Alert Level 3" was made after the planned suspension of public transportation was started.

The ward conducted a comprehensive inspection of the response to the Reiwa 1 East Japan Typhoon, and as a result plans to open the Primary Flood Evacuation Shelters at least 24 hours before the approach or passage of a typhoon, and the Secondary Flood Evacuation Shelters will be opened on the day of, but still before, the approach and passage of the typhoon [11].

Even in the Setagaya Ward Evacuation Information Judgment Criteria after the comprehensive inspection, "If it is assumed that evacuation information [Alert Level 4] will be issued at night, it will be issued in the evening." In this way, the timing of the announcement of [Alert Level 4] will not differ significantly from announcements made in the past. [32]

Table 8. Time series table at the time of the Typhoon in eastern Japan in the first year of Reiwa [33][34]

Date	Time	Weather Warnings/Advisories Evacuation Information Movement of Setagaya Ward Movement of Transportation operator	Rainfall intensity (mm/h)
Oct 10		Notification of plans to open voluntaryevacuation shelters	-
Oct 11	15:46	Heavy Rain Advisory	0.0
Oct 12	4:15	Heavy Rain Warning	0.5
	6:32	Flood Warning/Gale Warning	0.0
	10:00	Opening voluntary evacuation shelters	0.0
	14:00	Information to provide a warning on flooding [Level 3] A large-scale planned suspension of transportation was implemented from around 14:00 on the 12th all day long.	31.0
	14:45	Flood Evacuation of the Elderly, Etc. [Level 3] Voluntary evacuation shelters → Evacuation shelters	18.5
	15:40	Flood Evacuation Recommendation [Level 4]	25.5
	15:41	Heavy Rain Emergency Warning (Announced in western Tokyo)	
	15:50	Information on potential flooding [Level 4]	
	18:45	Flood Evacuation Instruction (emergency) [Level 4] (to outer embankment only)	13.5
	19:30	Flood Evacuation Instruction (emergency) [Level 4] (to the entire target area)	14.0
	22:00	Flood Disaster occurrence information [Level 5]	2.0
	22:34	Heavy Rain Emergency Warning	2.0
Oct 13	4:55	The evacuation instruction cancelled.	0.0

With this current plan in place, it would not be possible to safely evacuate approximately 30,000 evacuees using public transportation before the planned suspension of operations; this would lead to the previous situation where neighboring evacuation shelters became overcrowded.

Moreover, when the typhoon struck East Japan in 2019, it was not during an epidemic of an infectious disease such as COVID-19, but now it is necessary to keep in mind that, should a similar disaster occur again, it may be in combination with such an epidemic.

As clarified in the analysis of chapter (3) a considerably longer lead time is required to evacuate 28,040 evacuees.

In order to achieve this, it is necessary to take measures such as opening Primary Flood Evacuation Shelters, and at the same time opening voluntary evacuation shelters, as well as actively encouraging the general public in at-risk areas to evacuate as soon as possible.

Voluntary evacuation shelters that open early should be located far from the flood-risk areas, but within the limits that public transportation reaches without having to change trains and / or buses, so as not to reduce the capacity of the evacuation shelters near at-risk areas. Since the travelling time of public transportation shown in **Figure 12** is within about 30 minutes even by bus, it is considered that even the farthest evacuation shelter is not located at a burdensome distance. It is also considered beneficial for voluntary evacuees to evacuate to less crowded evacuation shelters. By doing so, confusion that may occur at the evacuation shelters on the day of an approaching typhoon could be alleviated.

In addition, the Cabinet Office has informed municipalities that they will be asked to open as many necessary evacuation shelters as possible, and as early as possible. [35]

(6) Evacuation plan for COVID-19 patients staying in their homes

a) Estimation of the number of patients receiving treatment at home and/or are waiting for a hospital or hotel bed to become available (assuming that the number of COVID-19 cases is still at its peak)

Since there is no data on the target area population in 2021, it is calculated by converting as shown in **Table 9**. Since the population ratios of the Tamagawa and Kinuta districts, which include the flood-risk areas, to Tokyo have

Table 9. Conversion of the 2020 population in the analysis target area to the 2021 population [19][36][37][38]

(People)

Date	Tokyo	Tamagawa +Kinuta	Target area
Jan 1,2020	13,384,925	389,955	54,808
ratio	1.0000	0.0282	0.0040
Jan 1,2021	13,843,525	391,046	54,842
ratio	1.0000	0.0282	0.0040

remained unchanged at 0.0282 in the last two years, it is judged that the population ratios of the flood-risk areas are also the same.

On the other hand, the peak number of COVID-19 patients staying in their homes in Tokyo was 39,592 on August 21, 2021, as shown in **Figure 8**.

From these findings, when λ is calculated in order to estimate the number of COVID-19 patients staying in their homes by Poisson distribution, $\lambda = 39{,}592 \times (54{,}842/13{,}843{,}525) \fallingdotseq 156.846$ people. Therefore, the probability mass function and the cumulative distribution function are obtained, as shown in **Figure 14**. From this, it is estimated that the number of COVID-19 patients staying in their homes in the Tama River flood-risk areas with a 95% confidence interval is 133–181.

Multiply this by an evacuation rate of 66.08% to the evacuation center designated by the Public Health Center (in the case of infected persons, the remaining 33.92% remain in their homes), and as a result, the number of evacuees to evacuation shelters is estimated to be 87.9–119.6.

The Tokyo Metropolitan Government provides private ambulances and dedicated transport vehicles arranged by the Tokyo Metropolitan Government as means of transportation for hospitalization and accommodation treatment.

There are 21 private-sector ambulance companies certified by the Tokyo Fire Department [39] in Setagaya Ward, and the number of certified ambulances is 36. However, only six of the companies to transport COVID-19 infected persons, which accounts for just eight ambulances, and it is difficult to reserve an ambulance. Thus, it is extremely difficult to transport the estimated 87.9–19.6 home-infected persons in the event of a disaster.

For this reason, regarding the evacuation plan for COVID-19 patients staying in their homes, in addition to preparing designated vehicles for transporting infected people in Setagaya Ward, if possible, it should be considered

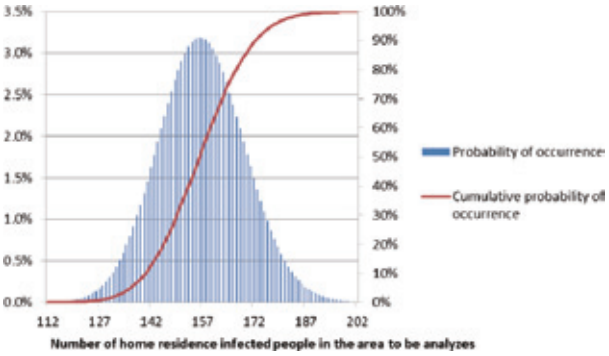

Figure 14. Probability of occurrence and cumulative probability of the number of COVID-19 patients staying in their homes based on Poisson distribution

to give priority to them in the event of evacuation from the flood-risk areas to evacuation hospitals/hotels designated by the Public Health Center, at least in the typhoon season. As mentioned above, it is urgently necessary to create a concrete evacuation plan that can realistically be followed in the event of a disaster.

It is also necessary to conclude an agreement with disaster transport agreements with private-sector ambulance companies.

5. Summary

In this paper, we specifically examined the flood evacuation plan from the Tama River flood-risk area in Setagaya Ward in the event of a typhoon approaching and passing under the conditions of an epidemic of an infectious disease such as COVID-19.

The verification results are summarized below.

[1] Based on the Tokyo Metropolitan Government's guidelines [16], the minimum occupying area of evacuation shelters per person is required to be at least 4.6 m^2.

[2] In order to evacuate approximately 30,000 evacuees, public transportation is essential, especially railways, and it is necessary to take railway lines into account when planning the location of evacuation shelters. It is clear that a review of the flood evacuation shelters in the Kinuta district is necessary, because the distribution of the evacuation centers is inadequate.

[3] In order to transport evacuees from the Tama River flood-risk areas in the Kinuta district, the transportation capacity is not sufficient using the regularly scheduled buses alone; it is also necessary to carry out shuttle transportation by charter buses.

[4] A considerably longer lead time is required to evacuate the estimated 28,040 evacuees. In order to achieve this,

it is necessary to take measures such as opening Primary Flood Evacuation Shelters, while at the same time opening voluntary evacuation shelters and actively encouraging the general population to evacuate as soon as possible.

REFERENCES

[1] COVID-19 Data Explorer - Our World in Data https://ourworldindata.org/explorers/coronavirus-data-explorer?zoomToSelection=true&time=2019-12-31..2021-08-31&facet=none&pickerSort=asc&pickerMetric=location&Metric=Confirmed+cases&Interval=New+per+day&Relative+to+Population=false&Align+outbreaks=false&country=~OWID_WRL (Last browse:Sep 1, 2021)

[2] National Institute of Infectious Diseases-Analysis of replacement of new coronavirus (SARS-CoV-2) N501Y mutant strain in Japan (IASR Vol. 42 pp.174 - 175: August 2021 issue) https://www.niid.go.jp/niid/ja/2019-ncov/2502-idsc/iasr-in/10606-498c02.html (Last browse:Sep 1, 2021)

[3] National Institute of Infectious Diseases-Recent infection status of new coronavirus infection, etc. (as of September 1, 2021) https://www.niid.go.jp/niid/ja/2019-ncov/10619-covid19-ab50th.html (Last browse:Sep 2, 2021)

[4] WHO-Tracking SARS-CoV-2 variants https://www.who.int/en/activities/tracking-SARS-CoV-2-variants/ (Last browse:Sep 1, 2021)

[5] Coronavirus (COVID-19) Vaccinations - Statistics and Research - Our World in Data https://ourworldindata.org/covid-vaccinations (Last browse:Sep 1, 2021)

[6] NHK Special Site- New coronavirus-Data in Tokyo https://www3.nhk.or.jp/news/special/coronavirus/data/pref/tokyo.html (Last browse:Sep 1, 2021)

[7] Tokyo Metropolitan Government: Bureau of Social Welfare and Public Health-Status of people who are positive for COVID-19 infection test https://catalog.data.metro.tokyo.lg.jp/dataset/t000010d0000000089/resource/54996023-7255-45c5-b5b0-60458d874715 https://stopcovid19.metro.tokyo.lg.jp/data/130001_tokyo_covid19_details_testing_positive_cases.csv (Last browse:Sep 1, 2021)

[8] Flood evacuation shelters in Setagaya Ward https://www.city.setagaya.lg.jp/mokuji/kurashi/005/003/d00186335.html (Last browse:Sep 15, 2021)

[9] Setagaya Ward: Flood evacuation shelter congestion confirmation system https://vacan.com/map/35.64337932,139.6506864,12?genre=evacuation-center&areaName=setagaya-ku-evacuation (Last browse:Sep 15, 2021)

[10] Setagaya Ward: About the ward's response to the COVID-19 at the evacuation shelter https://www.city.setagaya.lg.jp/theme/002/d00186327_d/fil/hinanjo_koronataiou.pdf (Last browse:Sep 15, 2021)

[11] Setagaya Ward: About the establishment and operation system of evacuation shelters in case of heavy wind and flood https://www.city.setagaya.lg.jp/mokuji/kurashi/005/003/005/d00186227_d/fil/2.pdf (Last browse:Sep 15, 2021)

[12] Setagaya Ward: Residents' briefing session on the ward's efforts to deal with flood damage caused by typhoon No. 19 in the first year of Reiwa (3rd) p9. https://www.city.setagaya.lg.jp/mokuji/kurashi/005/003/010/d00186621_d/fil/12.pdf (Last browse:Sep 15, 2021)

[13] Setagaya Ward: About the damage situation about typhoon No. 19 https://www.city.setagaya.lg.jp/mokuji/kurashi/005/003/005/d00183673_d/fil/6.pdf (Last browse:Sep 15, 2021)

[14] Population and number of households by number of lot in Setagaya Ward in 2020 https://www.city.setagaya.lg.jp/mokuji/kusei/001/003/004/d00183827.html (Last browse:Sep 15, 2021)

[15] 2020 Attitude Survey of Setagaya Residents (Disaster Preparations) p.41. https://www.city.setagaya.lg.jp/mokuji/kusei/006/003/d00187267_d/fil/31.pdf (Last browse:Sep 15, 2021)

[16] Tokyo Metropolitan government: Guidelines for Countermeasures against COVID-19 in Evacuation Shelters p.12. https://www.fukushihoken.metro.tokyo.lg.jp/joho/soshiki/syoushi/syoushi/hinanjo-guideline_COVID-19.files/honbun20200701.pdf (Last browse:Sep 15, 2021)

[17] Setagaya Ward: Evacuation shelter operation manual (standard version) [Supplement] "Countermeasures against infectious diseases such as COVID-19" https://www.city.setagaya.lg.jp/mokuji/kurashi/005/003/003/d00159069_d/fil/pdf2-1.pdf (Last browse:Sep 15, 2021)

[18] Setagaya Ward Local Disaster Management Plan (References) pp.156 - 161. https://www.city.setagaya.lg.jp/mokuji/kurashi/005/003/007/002/d00029991_d/fil/02.pdf (Last browse:Sep 15, 2021)

[19] Population and number of households by town in Setagaya Ward in 2020 https://www.city.setagaya.lg.jp/mokuji/kusei/001/003/002/d00183825.html (Last browse:Sep 15, 2021)

[20] Iruma City Local Disaster Management Plan (References) pp.25-26. http://www.city.iruma.saitama.jp/_res/projects/default_project/_page_/001/004/086/210319siryouhen.pdf (Last browse:Sep 15, 2021)

[21] Kashiwa City Local Disaster Management Plan (References) pp.32-36. https://www.city.kashiwa.lg.jp/documents/45/chiikibosaikeikakusiryo202103.pdf (Last browse:Sep 15, 2021)

[22] Kawagoe City Local Disaster Management Plan pp.2-38 - 2-39. https://www.city.kawagoe.saitama.jp/shisei/seisakushisaku/hoshinkeikaku/chiiki-seikatsu/chiikibousaikeikaku.files/1_hyousimokuji.pdf (Last browse: Sep 15,2021)

[23] Soka City Local Disaster Management Plan (References) pp.24-25. http://www.city.soka.saitama.jp/cont/s1004/shiryou.pdf (Last browse:Sep 15, 2021)

[24] Osaka City Local Disaster Management Plan p.89. https://www.city.osaka.lg.jp/kikikanrishitsu/cmsfiles/contents/0000011/11958/shinsai-r3-2-1.pdf (Last browse:Sep 15, 2021)

[25] Hidaka City Local Disaster Management Plan pp.155-156. https://www.city.hidaka.lg.jp/soshiki/somu/kikikanribosai/bosaishobo/shobobosaibohan/bosaikanrenjoho/1998.html

(Last browse:Sep 15, 2021)
[26] The Portal Site of Official Statistics of Japan: Statistics Map of Japan (jSTAT MAP)
https://jstatmap.e-stat.go.jp/jstatmap/main/base.html?1632189950906 (Last browse:Sep 15, 2021)
[27] Revised Urban Disaster Prevention Practice Handbook-Guide for urban development and district town development that is resilient to earthquakes p.86.: Edited by the Editorial Committee of the Urban Disaster Prevention Practice Handbook, Recommended by Ministry of Land, Infrastructure, Transport and Tourism
(Last browse:Sep 15, 2021)
[28] Setagaya Ward: Efforts based on measures against heavy wind and flood damage p.6.
https://www.city.setagaya.lg.jp/mokuji/kurashi/005/003/005/d00186227_d/fil/1.pdf (Last browse:Sep 15, 2021)
[29] Setagaya Ward: Response to evacuation person requiring support in preparation for flooding of the Tama River
https://www.city.setagaya.lg.jp/mokuji/kusei/002/d00192254_d/fil/3.pdf (Last browse:Sep 15, 2021)
[30] Disaster Management, Cabinet Office: Overview of Typhoon No. 19 etc.
http://www.bousai.go.jp/fusuigai/typhoonworking/pdf/houkoku/sanko2.pdf (Last browse:Sep 15, 2021)
[31] Disaster Management, Cabinet Office: Outline of heavy rain in July, 2020
http://www.bousai.go.jp/fusuigai/subtyphoonworking/pdf/dai3kai/siryo4.pdf (Last browse:Sep 15, 2021)
[32] Setagaya Ward Evacuation Information Judgment Criteria
https://www.city.setagaya.lg.jp/mokuji/kurashi/005/003/005/d00148933_d/fil/handankijun.pdf
(Last browse:Sep 15, 2021)
[33] Ward Notice "Setagaya" June 4, 2020 "Special issue to prepare for wind and flood damage"
https://www.city.setagaya.lg.jp/static/oshirase20200604/p02_001.html (Last browse:Sep 15, 2021)
[34] The Asahi Shimbun Digital: [Summary] Typhoon No. 19 information: Each transportation system is scheduled to be suspended
https://www.asahi.com/articles/ASMBB5WYQMBBUEHF00C.html (Last browse:Sep 15, 2021)
[35] Disaster Management, Cabinet Office: About facilitation of evacuation in future typhoons based on Typhoon No.10 in 2020 (Part 2) p.5.
http://www.bousai.go.jp/pdf/1008_enkatsu.pdf
(Last browse:Sep 15, 2021)
[36] Households and population in Tokyo based on the Basic Resident Register
https://www.toukei.metro.tokyo.lg.jp/juukiy/2020/jy20000001.htm (Last browse:Sep 1, 2021)
[37] Households and population in Tokyo based on the Basic Resident Register in 2021
https://www.toukei.metro.tokyo.lg.jp/juukiy/2021/jy21000001.htm (Last browse:Sep 1, 2021)
[38] Population and number of households by town in Setagaya Ward in 2021
https://www.city.setagaya.lg.jp/mokuji/kusei/001/003/002/d00189572.html (Last browse:Sep 1, 2021)
[39] Tokyo Fire Department: Transportation company certification display system for patients, etc.
https://www.tfd.metro.tokyo.lg.jp/hp-kyuusidouka/kanjahanso04_ninteiitiran.html (Last browse:Sep 15, 2021)