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A Study of Site Planning Integrated with Sustainable Stormwater Management in the Scale of District -Comparative Analysis Utilizing 3D Measurement Technology Part1-

Hikaru Shimazaki[1*], Tomoaki Tanaka[2]

[1] Ph.D. Student, Architecture and Urbanism Program, Graduate School of Science and Technology, Meiji University, Japan
[2] Professor, Department of Architecture, School of Science and Technology, Meiji University, Japan, D.Arch

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ABSTRACT

With the recent increase of short-duration rainfall, the capacity of urban drainage tends to be exceeded, and inland flood is increasing. Particularly, in highly urbanized areas with low ground surface permeability, it is necessary to manage stormwater flows adequately. The site planning integrated with sustainable stormwater management both in the scale of building and district will become increasingly important. In this study, we focused one in the scale of district. We conducted surveys using 3D measurement technology, targeting two types in the scale of district: a case where sustainable stormwater management has been prepared in the Kamisakunobe area, Takatsu-ku, Kawasaki City, and a case where the sustainable stormwater management was not sufficiently prepared in Kuji area, Takatsu-ku, Kawasaki City. By analyzing and comparing the 3D data obtained from the surveys in the two cases, we aimed to clarify the effectiveness of stormwater management and damage by identifying the relationship between topographical features and the risks caused by them. First, for the Damaged case, we produced a 3D section of the damaged area and verified the relationship between the damage and the topography. Next, we verified the effectiveness of sustainable stormwater management for the Prepared case by following the same procedure. Then, we compared the two cases, and we examined how the site planning integrated with sustainable stormwater management can be effective in scale of the district.

1. Introduction

In recent years, global climate is changing worldwide due to global warming. According to the report "AR6 Synthesis Report: Climate Change 2023" [1] published by the IPCC, in addition to rising land temperatures, sea surface, and atmospheric temperatures are also rising, and weather and climate extreme events are increasing. In Japan, the frequency of water-related disasters increased in recent

[1*] *Corresponding author.*
E-mail address: hikaru5266@gmail.com

years due to short-duration heavy rainfall and stronger typhoons. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) [2] reports that the total amount of flood damage in Japan during the 10 years from 2008 to 2017 was about 1.8 trillion yen, of which about 40% was caused by inland flood. These data indicate that the amount of rainfall exceeds the city's drainage capacity, resulting in an increasing number of cases of inland flood. In response to these damages, the Japanese government began promoting flood countermeasures based on the concept of River Basin Disaster Resilience and Sustainability by All [3] in 2020. In addition, in 2021, the Basic Plan for Housing and Living Standards was revised [4]. The plan includes the promotion of flood countermeasures for houses and residential areas through house renovation and embankment etc. to respond to the increase in flood damages in recent years. This shows that in Japan, there is an immediate issue of how to deal with flood damage. It is important to improve river and sewerage systems. However, many rivers in urban areas have no room for expand, which require a huge amount of time, labour, and money. This makes it difficult to immediately implement countermeasures in all areas. Therefore, even on a smaller scale, such as scale of a district or building, it is necessary to manage stormwater flow adequately. In such cases, site planning integrated with sustainable stormwater management will become important.

There are many studies on sustainable stormwater management in the fields of civil engineering, urbanism, and hydrology. Fujimura et al.'s study on stormwater infiltration [5,6] and Ishikawa et al.'s study on flood prevention in green space [7] show how effective stormwater harvesting and infiltration facilities are in preventing flood for an entire watershed. In addition, the study on topographical and geographical characteristics of flooded areas by Sato et al. [8] and the study on vulnerability factors of inland flood by Ozaki et al. [9] show that areas vulnerable to inland flood are affected by topography and manmade structures. However, these studies cover a very large area, and few of them show the detailed relationship between topography and buildings as in this study. This study uses 3D measurements for obtaining data, although the purpose of the study is different, the study of potential inundation locations in cities by Kim et al [10]. is simulated using high-precision 3D data. Kishi et al. [11,12] describe nested watersheds that is hierarchical structure of sub- or small watersheds. In this study, we focus on areas that are smaller units than small watersheds because we are targeting the scale of district. This study is a continuation and expansion of Tanaka et al.'s study on site design utilizing 3D measurement technology [13,14]. In this study, we focused on the scale of the district.

In this study, we aimed to clarify the effectiveness of stormwater management and damage by identifying the relationship between topographical features and the risks caused by them. We targeted two types in the scale of district: a case where sustainable stormwater management was prepared, and a case where the sustainable stormwater management was not sufficiently prepared. Firstly, data on topography, buildings, and trees in the targeted area are obtained using 3D measurement technology. Secondly, for the damaged cases, we produced axonometric drawings that show the cross-section of topography and buildings, hereafter called "3D section" of the affected area. For the prepared cases, we produced 3D sections, including the area around the stormwater management system. Thirdly, the relationship between topographic features and the resulting risks were clarified, and then the effectiveness of stormwater management and its relationship to damage were clarified. Then, we verified the relative effectiveness and damage of stormwater management. The flow of this research is shown in Figure. 1.

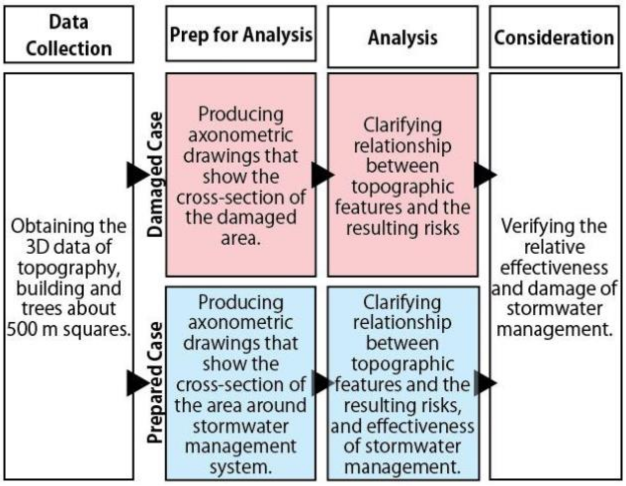


Fig. 1. Flow of research

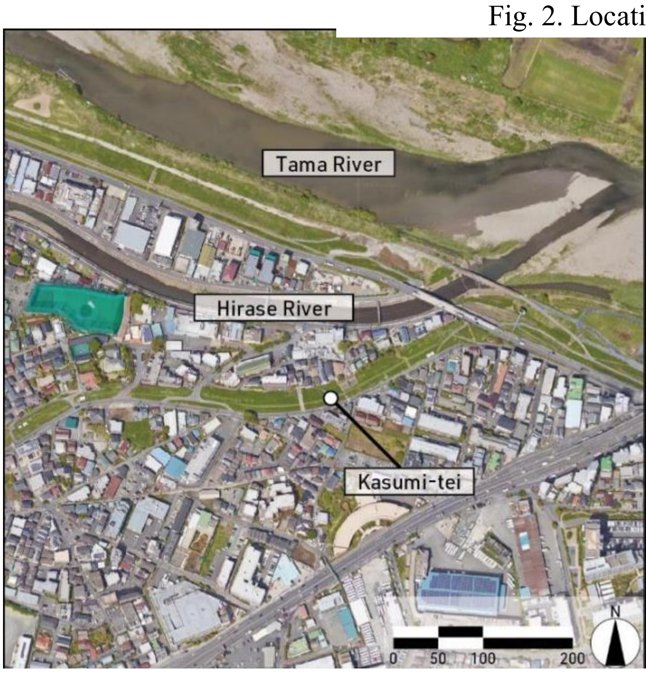
2. Study area and survey

2.1 *Study area*

In this study, as a damaged case, we investigated areas that were recently damaged by water-related disasters, especially inland flood. Next, we attempt to find a place where the damaged area is residential, not in the suburbs, and where there is no room for river expansion. As a result, the Kuji area in Kawasaki City was selected as a damaged case in this study. Kuji area was the area affected by Typhoon No. 19 in 2019. The Hirase River flows through the center of this area, merged with the Tama River to the east of the area. In addition, a former Kasumi-tei remains in the southern part of the area. Typhoon No. 19 in 2019 was a very powerful typhoon that caused extensive damage to the areas in the Kanto region. Kuji area was one of the most severely damaged areas, with inland flood. Furthermore, many buildings were submerged, and one person passed away.

As a prepared case study, we investigated an area that introduced stormwater management in the scale of district. Next, we attempted to find a place where rainwater management was introduced in a residential area with a certain density of inhabitants and where there was no room for the river to expand. As a result, the Kamisakunobe area in Kawasaki City was selected as a prepared case in this study. In the Kamisakunobe area, Minamihara Elementary School is located the south of the area, and the Kamisakunobe Housing Complex is located the north of the area. The Hirase River runs through the area from west to east in the north side of the area. There are two projects integrating stormwater management in the area. One is the Minamihara Elementary School, where its schoolyard is lower than the surrounding area and open for children to play, but it is prepared to store stormwater in case of heavy rainfall. Another is the Kamisakunobe B Regulating Pond, which is located underground in the housing complex. This facility is placed underground and invisible from the ground level. Basic information on both cases is shown in Figures 2 - 4.

Fig. 2. Location of two cases



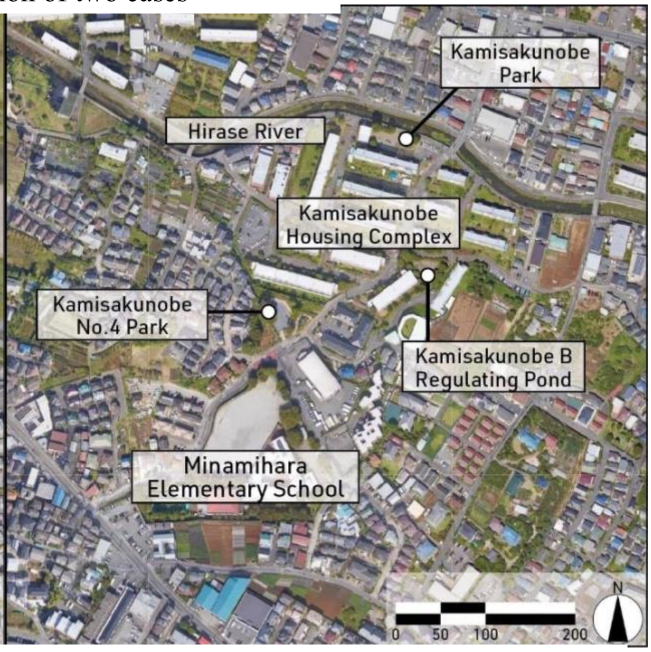


Fig. 3. Aerial photograph of Kuji area Fig. 4. Aerial photograph of the Kamisakunobe area

2.2 Process of obtaining 3D data

The Japanese government provides DEM data open to the public. However, the precision of the data is limited to allow an error of up to about 300 mm. In addition, the data does not contain any information on buildings and structures. While this data is effective for analysis for large areas such as entire watersheds, we considered it unsuitable for studies of relatively small areas such as the subject in this study. Therefore, we decided to obtain 3D data by ourselves. In recent years, equipments are becoming more inexpensive and more diverse. Technologies for the survey using 3D scanners, drones, and smartphones have become widely available. In this study, we utilized two types of 3D scanners to obtain the data of the targeted area. We conducted surveys in steps starting from 2017 for the Kamisakunobe area. For the Kuji area, we conducted the survey of the targeted area in 2023. In addition, we used different equipment to measure data in 2017-2019 and 2022. For the 2017-2019 surveys, we used a ground-based 3D scanner (Faro Focus 3D S120). This ground-based scanner takes about 8 minutes per scan, and while it can obtain a wide range of data with extremely high accuracy,

it is a time-consuming survey. In addition, it requires technical skills, such as adjusting the survey position to avoid creating blind spots, making it a difficult skill to master.
On the other hand, the new portable 3D scanner (Leica BLK2GO) is not as accurate and has a lower range than ground-based scanners, but it is faster and easier to operate. Therefore, we selected to use this new portable type of scanner for the surveys after 2022.

2.3 Results of surveys

We obtained 3D data for almost the entire targeted area successfully through the survey process described above. However, because the scans were taken from the road, it was not possible to obtain data of the rooftops or the data inside of private property. The obtained data were processed using the software that are the manufacture of each scanner provided. For the 3D scanner on a tripod, the data obtained at each location were registered to be combined, and noises caused by people, vehicles, etc., were removed. The same processes were applied to the data obtained by the portable scanner, and then the data were integrated to produce a set of data that represented the entire targeted area. The survey details are summarized in Table. 1. The results of the surveys are shown in Figure. 5.

Table. 1. Detail of survey

	Location	Tool	Date	Data size (GB)	Max height difference (m)	Measured area (m^2)
Kuji	Kuji, Takatsu Ward, Kawasaki City, Kanagawa, Japan	Portable 3D Scanner	2023/12/9	19.74	29.7	66613
Kamisakunobe	Kamisakunobe, Takatsu Ward, Kawasaki City, Kanagawa, Japan	3D Scanner on a tripod	2017.8*1	46.51*2	42.3	76859
			2018.8*1			
			2019.8*1			
		Portable 3D Scanner	2022/9/16	8.31		

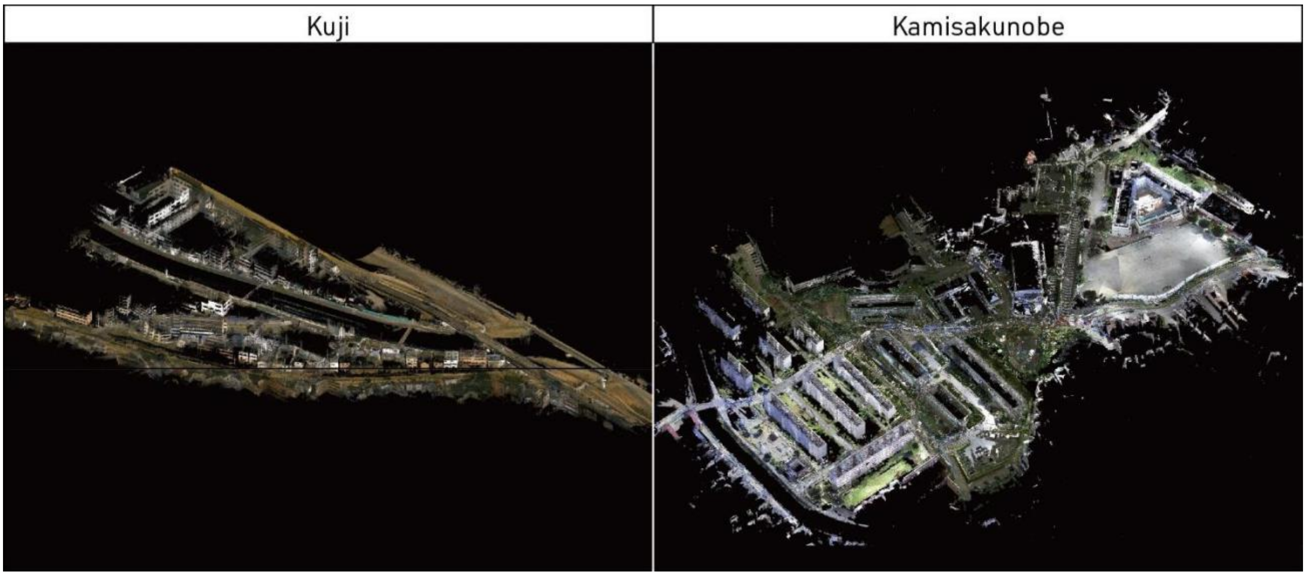


Fig. 5. Result of survey

3. Relationship between topography and risks

3.1 Subject of this chapter

In this chapter, we used the 3d data obtained through the process described in the previous chapter to analyze the relationship between topographical features and caused risks. For the damaged case, first, we represent inundated areas during the recent disaster on a map. Then, we produced 3D sections by cropping the 3D data centered on the damaged area. We used the 3D sections to clarify the relationship between the topographical features and the damage. For the prepared case, first, we represent prepared stormwater management facilities. Then, we produced 3D sections by cropping the 3D data centered on the damaged area.

3.2 Damage of Typhoon No.19 in 2019 in Kuji area

In the Kuji area, a total of 6 ha of the area along the Hirase River was inundated by Typhoon No. 19 in 2019. (Figures 6 and 7)

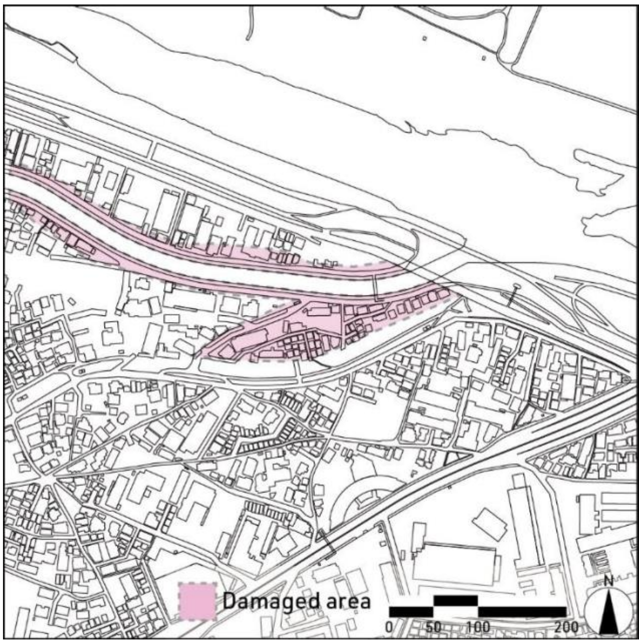


Fig. 6. Damaged area in 2019 with base map

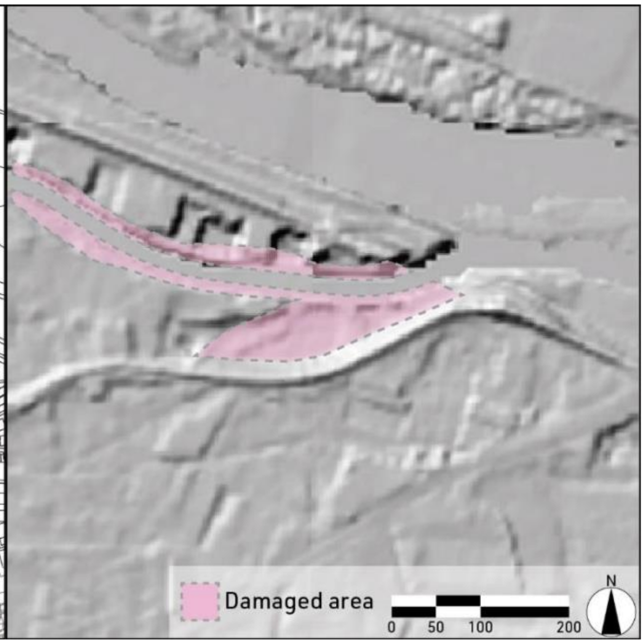


Fig. 7. Damaged area in 2019 with topographical map. “Produced from 陰影起伏図 （国土地理院).”

According to Kawasaki City’s report [15] that verify the cause of damage, the flood occurred due to three causes. (1) flood from drainage holes, (2) backwater from Tama River, and (3) flood from the dike of The Hirase River. At the time of the flood, the level of water of the Tama River was rising, and stormwater could not be discharged toward the Tama River from The Hirase River. This situation caused the water level of The Hirase River to rise, resulting the problem described in (1) and (3). In addition, since there is no dike at the confluence, water also entered from the Tama River. In addition, a hearing for the residents conducted by Kawasaki City reported that water also came out of manholes, so there is a possibility that inland flood also occurred simultaneously at several locations. This study basically targets damage caused by inland flood. Therefore, the backflow from the mainstream, as in (2), is considered to be too large to be handled in the scale of district in this study.

3.3 Relationship among buildings, topography, and risks in the Kuji area

We focused on the areas where damages were occurred by inundation besides the riverside areas. Then, we produced 3D sections of the damaged area, (Figures. 8 and 9).


Fig. 8. 3D section of Kuji area 1

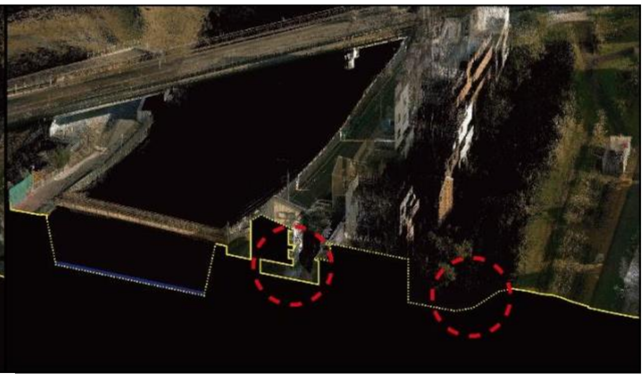


Fig. 9. 3D section of Kuji area 2

The right edge of Figure 8 shows the differences of levels, indicating that the center of this area is lower than the surrounding area. Figure 9 shows that the center of the area is also lower than the surrounding area, and the parking lot appears as if it is dug in. The Kasumi-tei that was constructed in the 18th century, is remaining in this area. Kasumi-tei is one of the traditional Japanese flood control measures to reduce damage to residential areas. By installing Kasumi-tei kinds of dike at certain distances from rivers and intentionally leading floodwaters between the Kasumi-tei and the rivers. Therefore, the level of the area between the Kasumi-tei and the river was originally lower than the surrounding area, and thus, it is vulnerable to flood damage. However, from the middle of the 20th century, the area between the Kasumi-tei and the Hirase River transformed residential area. In addition, the top level of Kasumi-tei on the right side is higher than the river bank on the left side, as shown in Figure 8. Therefore, the situation constrained by the surrounding ground levels makes it difficult to drain stormwater once it flows into the area. This topographical feature increases the damage from inland flood at the time of the 2019 disaster, this area had some overflow flood in addition to the inland flood. It is presumed that the water level in the Hirase River was rising very close to the breakpoint at that time. It is also presumed that the water level of the Hirase River is higher than the water level in the aforementioned area shown in Figure. 8, and thus, it was very difficult to drain the stormwater once it flew into the area. Therefore, in the Kuji area with the remaining Kasumi-tei, the situation constrained by the surrounding ground levels made it difficult for stormwater to drain out and caused more serious damage.

3.4 Stormwater management in the Kamisakunobe area

The schoolyard of Minamihara Elementary School, located to the south of the Kamisakunobe area is constructed in such way where the schoolyard is placed approximately 500mm lower than the surrounding area, as shown in Figure 9. Therefore, the schoolyard can store up to approximately 2200m^3 of stormwater as shown in Figure 10.

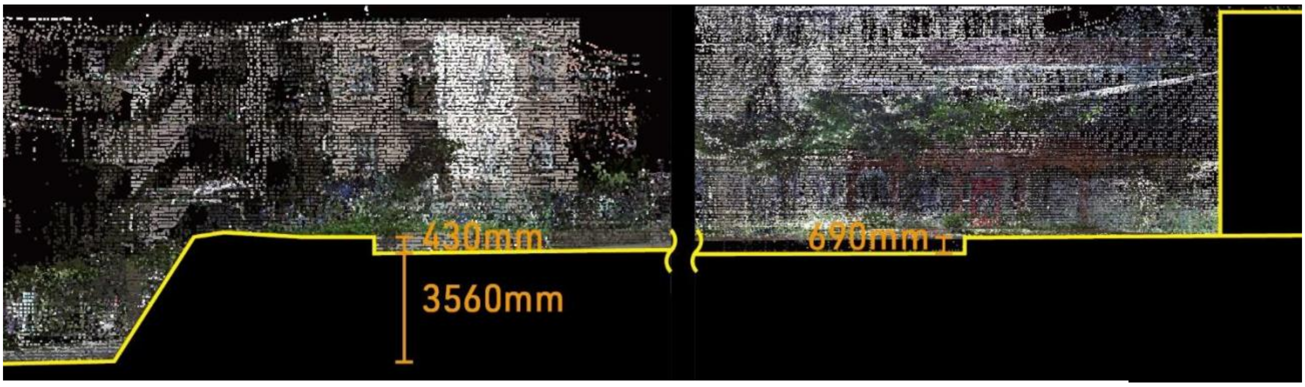


Fig. 9. Section of school yard of the Minamihara Elementary School

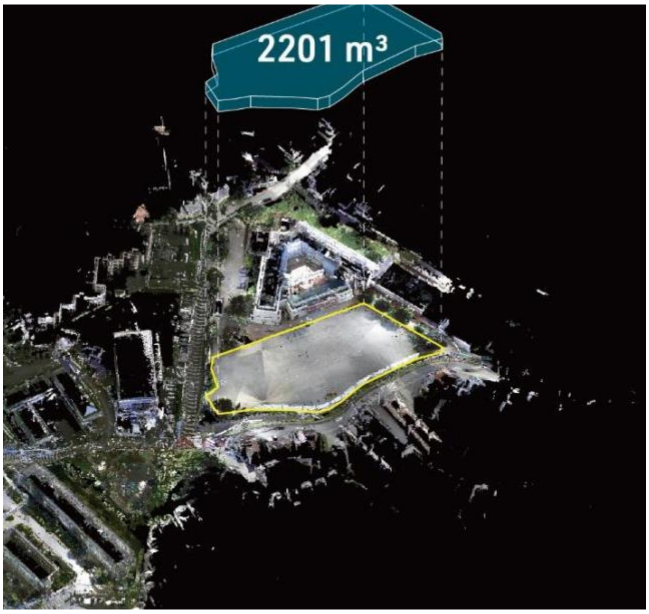


Fig. 10. Capacity of school yard of Minamihara Elementary School

Recently, there are records of damage from torrential rains in 1975 and from Typhoon No. 17 in 1975. However, no major damage has been reported since the completion of the Minamihara Elementary School and its schoolyard in 1986.

3.5 Relationship among buildings, topography, and risks in the Kamisakunobe area

We produced 3D sections focusing on the stormwater management facilities that are located in the area. (Figures 11, 12)

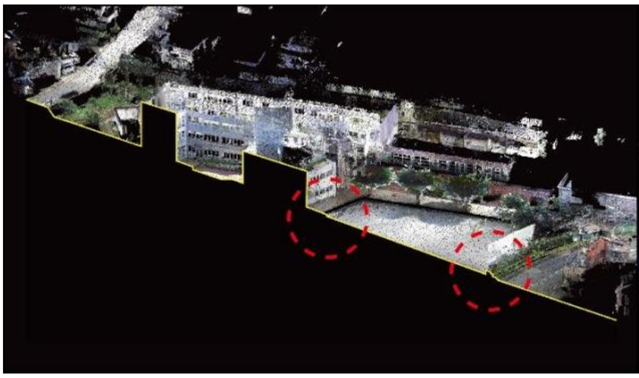


Fig. 11. 3D section of the Minamihara Elementary School area

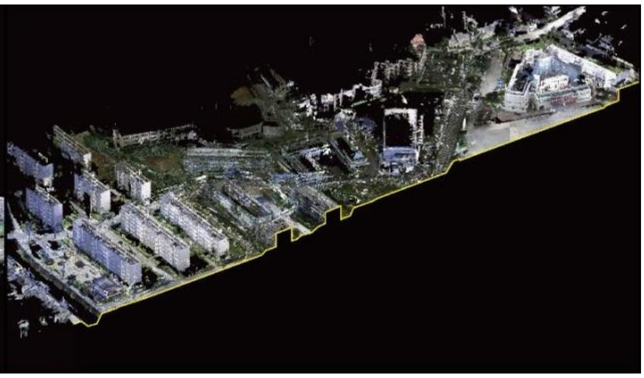


Fig. 12. 3D section of entire the Kamisakunobe area

Figure 12 shows that the topography near the river on the north side is relatively flat. This character of topography makes it difficult to drain stormwater once it flows into the area in the lower flat area. It is considered that the Kamisakunobe area has a risk because stormwater concentrates, flowing from the south side to the north side. Therefore, it is important to store stormwater at a location upstream of the stormwater flow path. If the schoolyard of the Minamihara Elementary School were not prepared to store stormwater, all the stormwater collected from the rainfall on the site will immediately flow into the northern part of the area.

The Kamisakunobe area has a risk, however, no damage has been reported since the completion of the the Minamihara Elementary School and its schoolyard, which stores stormwater upstream and thus functions to reduce the risk.

4. Conclusions

This study addressed the importance of Site planning integrated with sustainable stormwater management. The study particularly focused on the scale of district and selected adequate cases that represent issues in the scale of district. We selected Kuji area, Takatsu-ku, Kawasaki City, as a damaged case with insufficient stormwater management and the Kamisakunobe area, Takatsu-ku, Kawasaki City, as a prepared case with stormwater management. Because we considered that the data of the selected areas distributed by the government was not detailed enough. Therefore, firstly, we obtained 3D data by ourselves using our own 3D measurement technology. Secondly, we clarified the relationship between topographical features and damages in the damaged case. We also clarified the relationship between topographical features and the effects of stormwater management in the prepared case.

In Kuji area, the lack of countermeasures against the risks caused by the topographical features resulted both in the river flood and in the inland flood. On the other hand, in Kamisakunobe area the river flood occurred near the Hirase river in the past. In response to this vulnerability, one countermeasure of stormwater management was introduced by adding the function of stormwater storage to the schoolyard. It seems this countermeasure reduced the risk of the damage successfully. The result of survey is shown in Table. 2.

Table. 2. Result of survey

			River flooding	Inland flooding
District scale	Damaged cases		This case damaged without taking actions against risks caused by topographical features	This case damaged without taking actions against risks caused by topographical features
	Prepared cases		This case is storing stormwater in response to flood experiences. Thus, It seems this countermeasure reduced the risk of the damage successfully.	N / A

By comparing the results of both cases, it became evident that the risks caused by topographical features can be mitigated up to a certain extent in the scale of district. Because the flat terrain along the Hirase river and the sloped land toward the Mihamihara Elementary School are close to each other in distance in the Kamisakunobe area, it is effective to store stormwater upstream and reduce the stormwater that flows downstream. On the other hand, because flatter areas spread broadly in the Kuji area, it is difficult to introduce countermeasures like the one in the Kamisakunobe area due to the constraints of its topographical features. Therefore, it is necessary to take countermeasures such as drainage of rainwater that is stored in the space appears as if it is dug in, preventing rainwater from flowing into the area, and renovation of buildings that are possible to be damaged. It is necessary to further develop the research that determines effective countermeasures to reduce damages during and after the water-related disasters based on the findings in this research on the countermeasures to reduce the risks by stormwater storage. This study was limited by its discussion in the scale of district, which did not focus on smaller scale of discussion. This is the first one of a two-part series of papers, and the second paper will focus on cases in the scale of building to further deepen the discussion.

Acknowledgment
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Notes
*1 This study is ongoing since 2017. The data from 2017 to 2019 were taken in previous research. [16,17] Old records are missing, and detailed survey dates are unknown.
*2 As with *1, the older data have already registered and the size of each data is unknown

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