PREDICTION OF URBAN INUNDATION IN YOKOHAMA AND KAWASAKI CITY BY USING "S-UIPS"

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ABSTRACT

Rainwater removal system in Japan consists of the drainage network, the street gutter network, the pumping station, the water reclamation center and the urban rivers. The rainwater falls on the ground surface including roads goes into a drainage pipe through street-inlet tank or flows directly into the street gutter. And then the water is transported in urban rivers to the sea. Such a system is designed for rainfall intensity 50mm/h. in most urban area in Japan. Recently extreme weather become more remarkable in Japan, as a result of global climate change. Therefore the magnitude of typhoons become larger. And more serious inundation occurs due to a formation of linear rain band. The countermeasures come to be the urgent problem. The final goal of this series of study is to evaluate inundation risk in major cities in Japan, one of which is the Tsurumi River basins of Yokohama and Kawasaki City by using "S-uiPS" (Sekine's urban inundation Prediction System) developed by the first author. "S-uiPS" is the sophisticated and acurate prediction system which does not included any model parameters. Huge amount of data about all urban infrastructures is introduced in this computation; for example, road network, drainage pipes network, urban rivers, pumping station, underground reservoir, etc. As a result, time-series of digital maps of both inundation depth and river depth can been obtained just like video images. Such images can be the reliable information with high precision which should be used for mitigation.

Keywords: urban inundation, flooding in urban river, numerical prediction, torrential, rainwater removal system, inundation risk.

1. INTRODUCTION

The damage caused by torrential rain has been occurring frequently in Japan with the extremes of weather on a global scale, in 2019, several strong typhoons hit Japanese archipelagos. For example, Typhoon Hagibis caused significant damage in the Kanto, Koshin, and Tohoku regions. Each municipality has implemented not only hardware countermeasures but also software countermeasures such as hazard map creation, but there is scope for improvement in the accuracy. In order to prepare for the unprecedented heavy rainfall countermeasures in the future, accurate flood risk assessment and hazard map creation are desired. Previous studies by Shibuo et al. (2018) aimed at improving the accuracy of river water level prediction for the Tsurumi River have been conducted. In addition, Murase et al. (2018) conducted a study on inland water inundation analysis in Kasugai City, Aichi Prefecture, using the results of sewer internal water level measurement. In this study, using the sophisticated inundation prediction method "S-uiPS"(Sekine, 2011) developed by the first author, we evaluated the inundation risk in the eastern part of Yokohama and the eastern part of Kawasaki, and clarified the inundation process in the target area.

2. ANALYSIS OVERVIEW

2.1 Overview of the target area

This study area is made up of five drainage treatment zones of Kohoku, Chubu, Kanagawa, South, and North in Yokohama City and two of Iriezaki and Kase zone in Kawasaki City. The area is 239.3 km^2. The Tsurumi River basin exists in the center of this area. This river is the typical urban rivers in Japan, and the total length is 42.5 km in downstream direction. In this basin, severe inundation had occurred frequently until the end of last century. Other than this river, the Katabira River, the Ooka River and the smaller-size river are there in this area. The population density in this highly urbanize in Yokohama City and Kawasaki City is very high and is almost same as the value in the 23 wards of Tokyo.

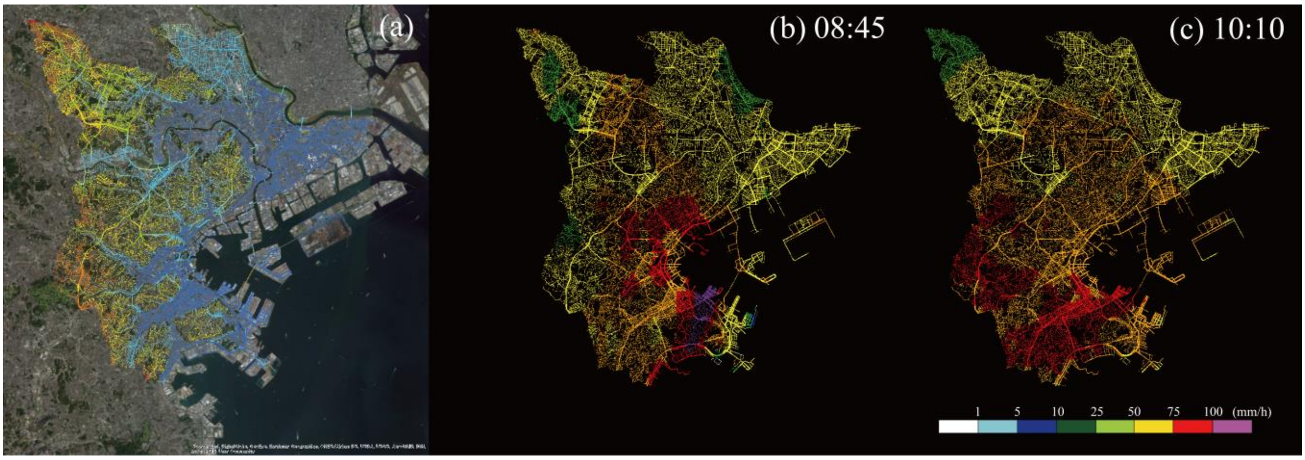

Figure 2. Contour maps in the target area: (a) elevation contour map, and contour map of rainfall intensity occurred on October 6, 2014 at (b) 8:45 and (c) 10:10.

In Figure. 2(a), the elevation contour map of ground surface is shown. The topography of western portion drawn in yellow or orange color is a mountainous terrain whose elevation is high. The coastal area and the area along the river, on the other hand, are lowlands. Thus, the target area has a large elevation difference between the western area and the eastern area, and therefore there exist many steep slope. Based on the above, one can easily expect that large-scale inundation damage can occur in lowlands if heavy torrential rains will occur in future.

2.2 Prediction calculation method

In this study, prediction of urban inundation was conducted by applying the sophisticated inundation prediction technique of "S-uiPS (Sekine’s urban inundation Prediction System)" which was developed by the first author. In highly urbanized areas in Yokohama City and Kawasaki City, the roads are paved with asphalt and the buildings are densely packed in blocks, so that rainwater hardly penetrates into the ground. Therefore, the rainwater which falls on the ground surface of the urban area is drained into the drainage system of rainwater consisting of drainage pipes, urban rivers and drainage facilities including the pumping stations and water reclamation centers. The flow of rainwater on roads, in drainage pipes and rivers can be solved on the basis of governing equations because these infrastructure was created artificially and the structure information were in our hand. After developing the database about such urban infrastructure in computer domain, we can conduct the prediction of inundation in urbanize area. S-uiPS can allow us to make such prediction accurately. According to the previous verification in 23 wards of Tokyo (Sekine et al., 2017), it was found that the prediction error was less than 5cm in inundation depth. S-uiPS does not include any parameters to be tuned up and any assumptions, and computation is done only based on the principle.

2.3 Rainfall event and some more conditions in this computation

During the period from 18:00 on October 4 to 12:00 on October 6 in 2014, torrential rainfall occurred in Kanagawa Prefecture, and the amount of total rainfall was 352.0mm at AMeDAS station in Yokohama. Rain started to fall in the night of October 4 due to the stagnant of barometric pressure front above the Kanto area, and then Typhoon migrated in the vicinity of Kanagawa prefecture in northeast direction in the morning of October 6. In this study, computation was conducted by using XRAIN data which was measured by the X-band radar system of the Ministry of Land, Infrastructure, Transport and Tourism of Japanese Government. According to XRAIN, we can know the rainfall intensity every one minute, and the spatial resolution of 250m square. Therefore, it is possible to reproduce faithfully the rainfall event. In this paper, results of computation from 6:15 to 11:00 on October 6, 2014 was explain to discussion. Figure 2 (b) and (c) shows the examples of contour map of the rainfall intensity during this heavy rainfall event.

3. RESULT

Figure 3 is the results of computation by using XRAIN data to reproduce what inundation occurred on October 6, 2014. Left column of in Figure 3 denotes the contour map of the inundation depth at 8:00, 10:00, and 11:00 respectively, and the right one is the contour map of the drainage fullness at 8:00, 9:00, and 11:00, respectively. In the left figure, the relative water depth of the river is also shown with several grade of blue line.

In the period from 6:15 to 8:00, rain clouds have moved northwest, and the average rainfall over this area was about 20 to 50 mm /h. During the time of 30 minutes from 7:30 to 8:00, rainfall intensity became over 50 mm/h mainly in the western part of this area. According to the results of the inundation depth at 8:00, inundation started in the entire area, but the inundation depth was about 0.1 m or less, and no serious inundation occurred. One can see how concentrates the rainwater in drainage pipe from the upper-right contour map of Figure 3 at 8:00. The red drainage pipe denotes the water in the pipe has already been filled with rainwater. No inundation

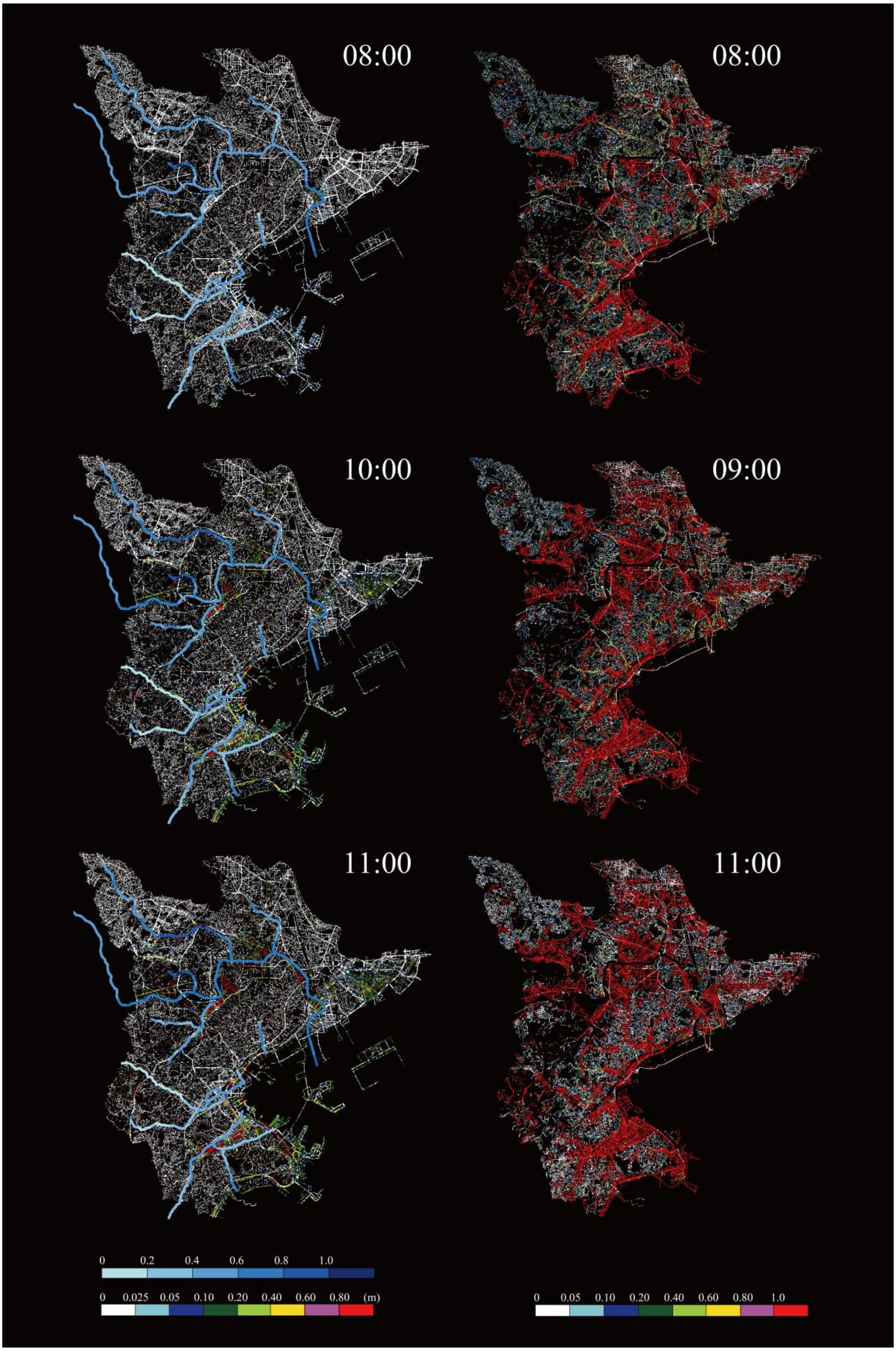

Figure 3. Contour map of Inundation depth on road (in left) and state in drainage pipe predicted for the rainfall event on October 6, 2014.

has yet occurred there even though the drainage pipe attains such full-packed state due to the local rainfall exceeding the designed rainfall intensity. At this stage, the rainwater removal system worked normally. The relative depth of each river did not increase significantly between 6:15 and 8:00.

During the time from 8:00 to 10:00, heavy rainfall of 75 mm per hour and then the one more than 100 mm per hour occurred in this area. As is seen in the middle-right of Figure 3, the number of drainage pipe in full-packed state increased in comparison with the upper-right contour map. Inundation occurred on the road in lowland area during this time. At 10:00, inundation depth in the center of Yokohama City became about 0.1-0.5m. Situation was same in lowlands along the Tsurumi River and in the eastern part of Kawasaki city. In some area there, there are some location whose inundation depth is 0.8m or more than it. Flooding started to occur at the same time in several urban rivers including the Tsurumi River. It is because rainwater had been transported in drainage pipes to the rivers and the flow discharge in the river increased rapidly.

Finally, during the time from 10:00 to 11:00, inundation became more serious. During the first 30 minutes from 10:00, rainfall exceeding 50 mm/h occurred over the entire area. In the southern part of this area, the rainfall exceeding 75 mm/h occurred for the 20 minutes from 10:00. It is obvious that the area of remarkable inundation are same as that mentioned above and the depth there became much larger. As to the river flooding, overflow was not predicted from the Katabira River and the Ooka River, which is coincide with the actual event. From 10:30 to 11:00, the rainfall intensity decreased to be less than the designed rainfall intensity. Because the ability to remove the rainwater on road became larger than the rainfall intensity, the area of Inundation was reduced at 11:00.

The results are summarized above. Even if the rainfall exceeds the designed rainfall intensity, the rainwater removal system is functioning normally for about 30 minutes. However, when the rainfall with such a level rains for more than one hour, the drainage pipe attains the full-packed state and the inundation depth grows larger in lowlands because drainage pipe cannot remove the water on the ground surface. But even if rainfall intensity exceeded the designed value over the entire area, the places where inundation occurred were limited, and no large inundation depth was predicted in the areas far from the river. When the rain weakens, the of full-packed in drainage pipe is improved, and inundation itself starts to disappear gradually.

4. CONCLUSIONS

In this study, inundation prediction was conducted in Yokohama City and Kawasaki City in Kanagawa Prefecture on October 6, 2014 by using the XRAIN data. As this study, the area where inundation depth is relatively higher were found in these cities. It was also confirmed that the inundation depth becomes 0.8m or more than it in the lowlands. In addition, the characteristics of rainwater removal system including drainage pipe and urban river was made clear. when the rainfall weakened, the sewage fill rate decreased at high altitudes, but there were still many pipes with a fill factor of 1 in lowlands, and the drainage function did not recover immediately.

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