STUDY ON SUPPORT OF EVACUATION USING HAZARD MAP FOR OVERFLOW

YOSHIYA OGAWA
Kinki Community Development Center, 1-7-31 Otemae, Chuo-ku, Osaka, Japan, ogawa-yoshiya@hotmail.co.jp

MASANORI SERA
Kinsoku Ltd, 6 Kamitoba Omizo, Minami-ku, Kyoto-city, Kyoto, Japan, m_sera@kinsoku.net

KOTARO KUSAKAWA
Department of Civil and Environmental Engineering, Faculty of Science and Engineering, Setsunan University, 17-8 Ikeda-Nakamachi, Neyagawa, Osaka, Japan, k3s1k1w1k53t1r53@docomo.ne.jp

KOSUKE MORII
Department of Civil and Environmental Engineering, Faculty of Science and Engineering, Setsunan University, 17-8 Ikeda-Nakamachi, Neyagawa, Osaka, Japan, t.m.f.km070418@gmail.com

AKITSUGU KAJITANI
Department of Civil and Environmental Engineering, Faculty of Science and Engineering, Setsunan University, 17-8 Ikeda-Nakamachi, Neyagawa, Osaka, Japan, tsugu_aki1020@outlook.jp

ABSTRACT

The area around the Ogura-Ike Reclaimed Land, which spreads on the left bank of the Uji River, is mostly composed of fields, but also has residential areas. The Ogura-Ike Reclaimed Land is located at the lowest altitude of the Yamashiro Basin. Therefore, the Ogura-Ike and Kumiyama drainage stations were installed to counter possible flooding. A flood event with the same level as the flood caused by Typhoon No. 13 in September 1953 has not occurred. However, in recent years, heavy rains and other factors have caused flooding in both levee and non-levee areas of the Kizu and Katsura rivers in the Yodo River Basin. The possibility of flooding in the Uji River is high. This study used flood simulations and field studies to determine how evacuations could be safely conducted using flood hazard maps distributed to each household. The conducted flood simulation showed that the water overflowing from the Uji River flows into the Ogura-Ike Reclaimed Land at altitude. Our field studies confirmed the presence of several manholes. Care has to be exercised when moving to the evacuation sites because manhole covers are likely to open when flooding begins. In addition, the hazard map for a particular region shows little information on the neighboring regions; hence, it is necessary to be aware when considering the evacuation behavior. In summary, this study shows that evacuation could be safely conducted using hazard maps.

Keywords: Ogura-Ike Reclaimed Land, hazard map, evacuation, simulation, field study

1. INTRODUCTION

In recent years, flooding in both levee and non-levee areas has occurred in many parts of Japan on an annual basis due to abnormal weather phenomena. The lives and assets of many residents have been lost. In Japan, measures to improve river management are implemented in accordance with the basic policy for river improvement and the river improvement plan (Ministry of Land, Infrastructure, Transport and Tourism, 1997) established with the revision of the River Law in 1997. Flood control measures that have been implemented to date have focused on hardware-related measures, such as dams and levees. Owing to these measures, flood control safety has been significantly improved. However, the facilities constructed as hardware countermeasures were designed for the scales of flooding experienced in the past. These measures are not guaranteed to withstand phenomena occurring on scales exceeding those experienced in the past. Moreover, the degree of damage occurring when a structure such as a levee is destroyed is extremely large.

Therefore, river improvement using “non-structural measures” (a “damage mitigation method independent of structures”) is being promoted. Hazard maps became mandatory with the revision of the Flood Control Act in July 2005 and were consequently prepared and published throughout Japan. Following the further revision of the Flood Control Act in 2015, an “Estimated Flood Inundation Area Map” based on “the largest possible rainfall” was published (Ministry of Land, Infrastructure, Transport and Tourism, 2015). In addition, a disaster prevention action plan was defined and placed in operation (Ministry of Land, Infrastructure, Transport and

Tourism, 2016). However, as reported by Takagi et al. (2019), the public awareness of hazard maps is not very high at approximately 50%. Takagi et al. (2019) also pointed out that citizens with a high awareness of the hazard maps tend to display the appropriate evacuation behavior, but those who are not aware of the hazard maps tend not to evacuate.

This study focused on the Ogura-Ike Reclaimed Land, which spreads on the left bank of the Uji River flowing through the central part of the Yodo River Basin. The Yodo River Basin is a midstream area, where the Uji (Yodo), Kizu, and Katsura rivers join and flow into Osaka Bay. Lake Biwa, which is the largest lake in Japan, is located upstream of the Uji River. The Yodo River Basin contains some of the most economically productive cities in Japan, such as Kyoto City in its central part and Osaka City in its lower reaches. In the Yodo River tributaries (Katsura and Kizu rivers), the recent change in weather has resulted to flooding in both levee and non-levee areas, thereby causing damage to the Arashiyama area (Katsura River area), which is a popular tourist destination. This damage was reported in the following publications: for the Katsura River basin: 2013 Typhoon No. 18 (Ministry of Land, Infrastructure, Transport and Tourism Kinki Regional Development Bureau Yodogawa River Office, 2013) and 2014 Typhoon No. 11 (Ministry of Land, Infrastructure, Transport and Tourism Kinki Regional Development Bureau, 2014); and for the Kizu River basin: 2017 Typhoon 21 (Ministry of Land, Infrastructure, Transport and Tourism Kinki Regional Development Bureau Kizugawa-jouryu River Office, 2017). The Uji River has not suffered a major flood in recent years. However, the situation is far from safe with the 2013 flood causing a leak (Ministry of Land, Infrastructure, Transport and Tourism Kinki Regional Development Bureau, 2019). In the Uji River, the levee collapsed due to the flood caused by the heavy rain of Typhoon No. 13 in 1953. The break point of the levee was approximately 2 km downstream of the Kangetsu bridge. The break in the embankment was approximately 450 m in length. Approximately 2880 ha around the Ogura-Ike Reclaimed Land was flooded for 25 days. Since then, the Ogura-Ike Reclaimed Land has not suffered a similar flooding from the Amagase Dam or river improvement works at this point of collapse. Future huge events like heavy rains may cause a high possibility of Uji River flooding.

The Ogura-Ike Reclaimed Land is a region where the former Ogura pond was transformed into a field by a reclamation project responding to the famine that occurred in the early Showa era. Its altitude is almost the same as that of the original Ogura Pond. In other words, the Ogura-Ike Reclaimed Land is located at the lowest elevation in the Yamashiro Basin, where water is likely to collect when external or internal floods occur. The Ogura-Ike and Kumiyama drainage stations were installed in anticipation of such events. It is assumed that receiving necessary information in the event of a flood will be difficult for local residents because the area is separated by administrative boundaries, such as Fushimi-ku, Kyoto, Uji-shi, and Kumiyama-cho.

The aims of this study are as follows: (1) determine the inflection point and the flow direction using a simulation because these two factors are not indicated in the hazard map distributed to each household; and (2) explore how evacuations could be safely conducted by supplementing information that are not provided on the current hazard maps. This is in consideration to the fact that a residential area has been formed near the Ogura-Ike Reclaimed Land, and field studies must clarify what information should be provided to ensure that evacuation procedures are safely conducted.

2. FLOOD ANALYSIS

2.1 Flood analysis using iRIC software

In this study, the flood analysis of the Ogura-Ike Reclaimed Land was conducted using iRIC software (Ver. 3.0), which allows for a two-dimensional (2D) flood analysis. The Nays2DFlood solver (ver. 5.0) in iRIC is a solver for the flood flow analysis based on an unsteady plane 2D flow calculation using the boundary conditions in generalized curved coordinates. The continuity equation and the equations of motion in this model take the following forms:

Continuity equation:

$$\frac{\partial h}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hv)}{\partial y}=q+r \tag{1}$$

Equations of motion:

$$\frac{\partial (uh)}{\partial t}+\frac{\partial (hu^2)}{\partial x}+\frac{\partial (huv)}{\partial y}=-hg\frac{\partial H}{\partial x}-\frac{\tau_x}{\rho}+D^x \tag{2}$$

$$\frac{\partial (vh)}{\partial t}+\frac{\partial (huv)}{\partial x}+\frac{\partial (hv^2)}{\partial y}=-hg\frac{\partial H}{\partial y}-\frac{\tau_y}{\rho}+D^y \tag{3}$$

where,

$$\frac{\tau_x}{\rho} = C_f u\sqrt{u^2+v^2} \quad \frac{\tau_y}{\rho} = C_f v\sqrt{u^2+v^2} \tag{4}$$

$$D^x = \frac{\partial}{\partial x}\left[v_t \frac{\partial(uh)}{\partial x}\right] + \frac{\partial}{\partial y}\left[v_t \frac{\partial(uh)}{\partial y}\right] \tag{5}$$

$$D^y = \frac{\partial}{\partial x}\left[v_t \frac{\partial(vh)}{\partial x}\right] + \frac{\partial}{\partial y}\left[v_t \frac{\partial(vh)}{\partial y}\right] \tag{6}$$

h is the water depth; *t* is time; *u* is the flow velocity in the x-direction; *v* is the flow velocity in the y-direction; *q* is the inflow through a box culvert, a sluice pipe, or pump per unit area; *r* is the rainfall; *g* is the gravitational acceleration; *H* is the water surface elevation; τ_x is the riverbed shear stress in the x-direction; τ_y is the riverbed shear stress in the y-direction; C_f is the riverbed friction coefficient; v_t is the eddy viscosity coefficient; and ρ is the water density.

2.2 Conditions

The study area comprises a three-river junction area that includes the Ogura-Ike drained land of the Lake Biwa-Yodo River Basin in Kinki District, Japan (Figure 1). Table 1 presents the simulation conditions. We imposed the water discharge shown in Table 1 at the upstream boundary. The flow at the upstream end of the Uji River was taken from the flood data corresponding to 21:00 on August 10, 2014, which was the time of the largest flow among the discharge data observed and released at the Uji observatory. In this study, this flow was multiplied by 1.15. The flow at the upstream ends of the Katsura River and Kizu River was set to the corresponding flows measured during the period selected for the upstream end of the Uji River.

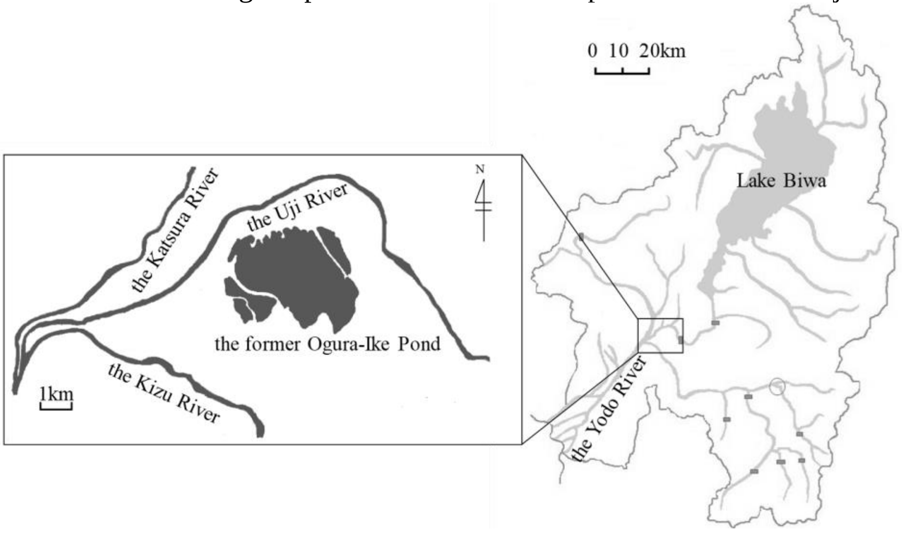


Figure 1. Location of the Ogura-Ike pond in the junction area of three rivers in the Lake Biwa-Yodo River Basin. The square area indicates the flood area covered by the analysis.

2.3 Results and discussion

The results of the analysis are illustrated in Figure 2. In this analysis, it was assumed that the levee does not collapse. The place where the water level was higher than the embankment height was designated as the flood point. At 35.5 h, after the start of the calculation, flooding was confirmed on the left and right levees around the location at 48.4 km. The flood lasted for approximately 2 h. The downstream side was narrower than the upstream side of the flooding location; hence, the flow down the river was assumed to be inhibited. It was established that flooding could occur in places where residential areas and factories are densely packed. As a confirmation, some of the floodwaters that overflowed on the left levee side flowed downstream along the levee. Further, it was confirmed that most of the floodwaters flowed northwest.

Table 1. Analysis conditions for the three rivers.

Data items	Parameters
Area of the region analyzed	77.4 km^2, including the following reaches: 0.0–5.4 km for the Katsura River 34.0–50.0 km for the Uji River 0.0–5.8 km for the Kizu River
River channel conditions	Survey of the river channel in 2015 Digital elevation model (DEM) data with a 5 m mesh in 2016
Flood flow (Upstream end Setting)	Hydrograph of the 13th typhoon in 2014 (from 10:00 on 8/9 to 09:00 on 8/16) Maximum: 2036 m^3/s for the Katsura River Maximum: 1917 m^3/s for the Uji River (※1667 × 1.15) Maximum: 3497 m^3/s for the Kizu River
Downstream end setting	34.0 km for the Yodo River, free discharge
Analysis meshes	25 m × 25 m
Manning's roughness coefficient	0.025 $m^{-1/3} \times s$

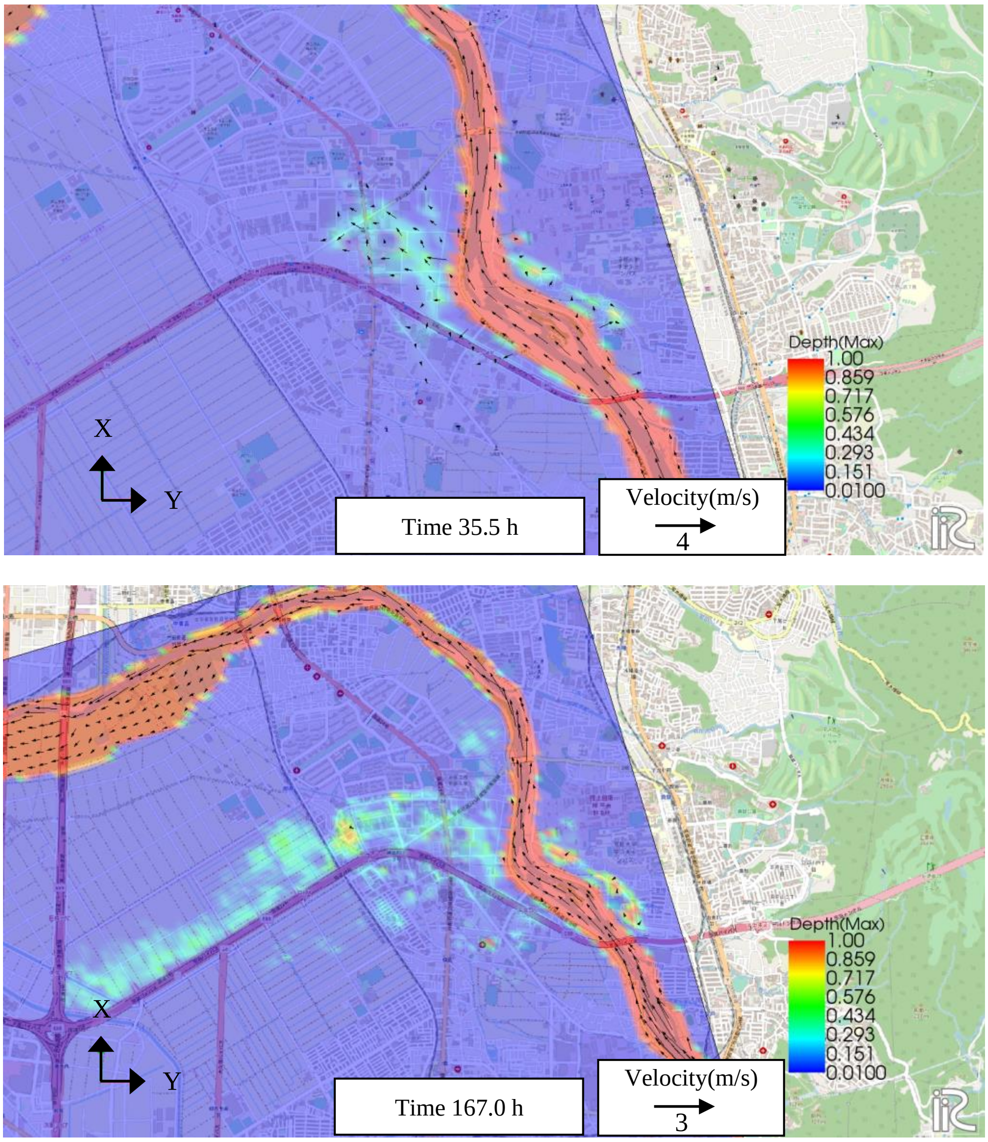


Figure 2. Flood point and flood propagation (upper figure: at the beginning of the flood; lower figure: flood propagation).

3. FIELD STUDIES

3.1 Mukojima area, Fushimi-ku, Kyoto

Figure 3 depicts the manhole distribution obtained from the field study. A total of 172 manholes can be seen on roads and sidewalks. In addition, the manhole locations had no regularity, such as “the center of the road.”

Figure 4 shows the elementary school designated as an evacuation center. A movable gate was installed at the entrance of the elementary school. The structure is usually locked, and the school premises could not be entered or exited freely. In addition, the school had fences.

Figure 3. Manhole locations obtained from the study.

Figure 5 depicts the passage connecting east and west. The Kintetsu Kyoto Line operates from north to south (Figure 3). In the scope of the study, the Kintetsu Kyoto Line has an embankment structure.

Figure 6 shows the housing situation in the area west (on the left side) of the Kintetsu Kyoto line (the line is shown in Figure 3). The photograph shown in the left of Figure 6 was taken from the levee of the Uji River. The heights of the roof of the house and the levee were almost the same. As for the housing conditions at the survey points, most of them are detached houses.

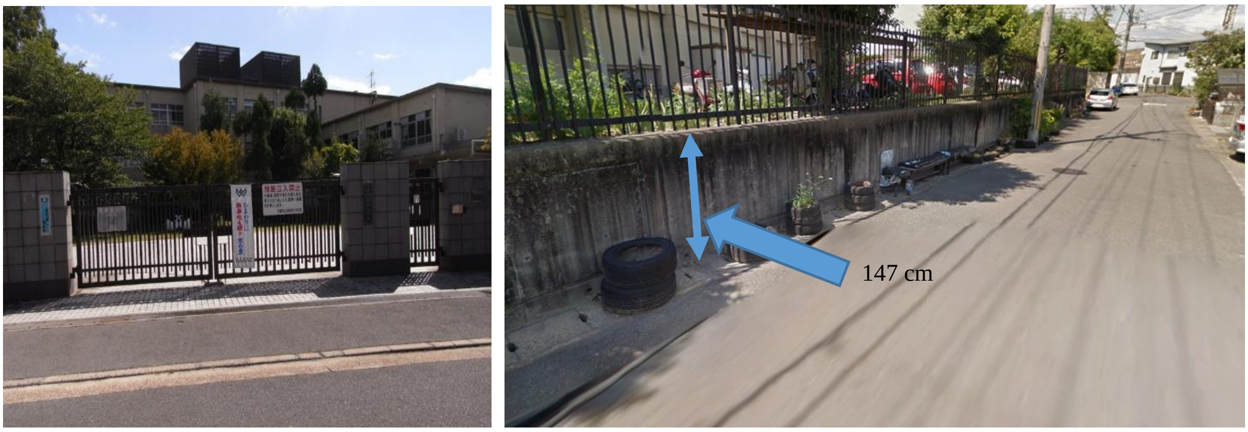


Figure 4. Elementary school designated as evacuation centers.

Figure 5. Passage connecting east and west.

Figure 6. Housing conditions in the studied area.

3.2 Area in Fushimi-ku, Kyoto, and Uji

Figure 7 illustrates the housing status of the area, including Fushimi-ku, Kyoto, and Uji (to the right of Mukaijima Station (Figure 3)). Most of the dwellings consist of apartments, and the entrances of the apartment houses in this area have many open places.

The characteristic structures that exist near the locations of the signboard installations were displayed with unique names, but for the adjacent Kyoto City, the descriptions were simplified (e.g., “elementary school” and “junior high school”) (Figure 8).

Figure 7. Housing conditions in the study area.

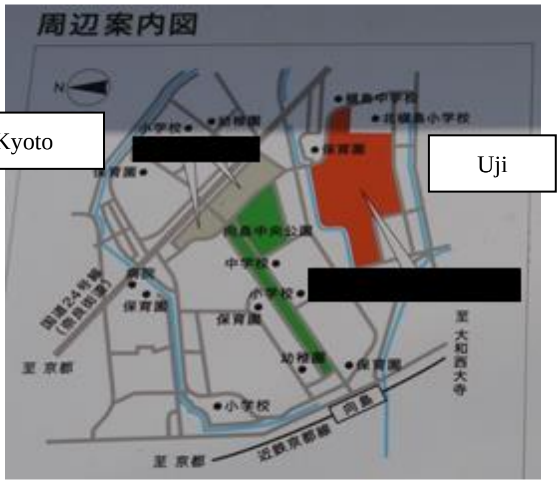
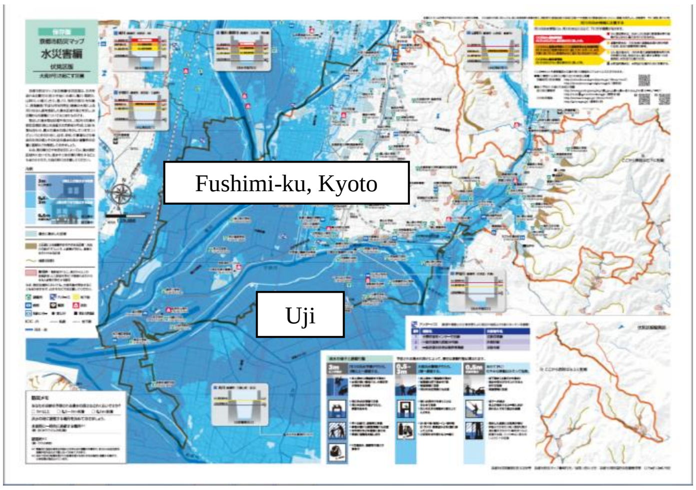


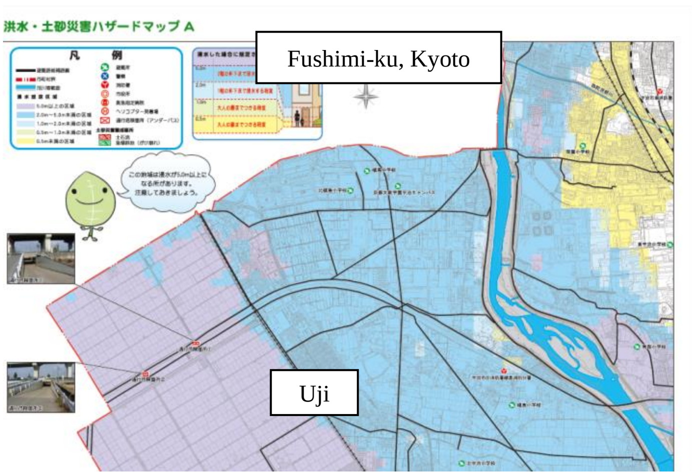
Figure 8. Example of information on a board installed in Uji city.

3.3 Hazard maps

Figure 9 depicts the hazard maps of Fushimi-ku, Kyoto (Kyoto City, 2018), and Uji (Uji City, 2018). Each hazard map has been created to cover a large area. Hence, they do not include any descriptions of "gutters," "waterways," "manholes," and other features, which could be assumed as obstacles when evacuating to evacuation centers. In addition, no information on the evacuation centers in the adjacent Uji city appeared on the hazard map of Fushimi-ku, Kyoto City. Similarly, the hazard map of Uji City does not include information on Fushimi-ku, Kyoto City. The color coding of the hazard maps represents the differences in inundation depth. The points, at which the inundation depths reached a maximum, are indicated. No descriptions of the flooding locations or directions of flow of the flood waters are provided. Furthermore, the maps are annotated in Japanese and not in foreign languages (e.g., English or Chinese). Therefore, the hazard maps are difficult to interpret for foreign tourists and foreigners unfamiliar with Japanese.



(a)



(b)

Figure 9. (a) Hazard map of Fushimi-ku, Kyoto. (b) Hazard map of Uji.

4. CONCLUSIONS

This study was conducted with the aim of establishing how the distribution of hazard maps to each household could contribute to a safe evacuation. The flooding locations and the flow directions of the flood were clarified in the flood simulation. As a recommendation for the evacuation drill, residents should plan their evacuation behavior considering this information, as well as the drill that assumes the flooding point and the direction of the floodwater flow. The field studies also revealed the following points:

1. Manholes are installed irregularly on roads and sidewalks. The evacuation behavior after inundation has started is likely to cause manholes to fall off and cause obstruction; hence, evacuation must proceed to altitudes higher than that of the home from which residents are evacuating.
2. Electric locks are often installed in apartment houses to prevent random people from coming and going. Residents are advised to check with their local government about the condition of the neighboring apartment buildings.
3. It is highly probable that the hazard map does not contain information on the neighboring government evacuation centers and excludes other important information. Therefore, we recommend that residents check their homes and the nearest evacuation centers beforehand and add possible important information.

ACKNOWLEDGMENTS

We would like to thank the members of the Yodogawa Basin Study Group for their suggestions in conducting this study. We would also like to thank Editage (www.editage.com) for English language editing.

REFERENCES

iRIC Software. https://i-ric.org/en/about/

Kyoto City (2018). http://www.city.kyoto.lg.jp/gyozai/page/0000086399.html (in Japanese)

Ministry of Land, Infrastructure, Transport and Tourism (1997). About river maintenance basic policy, river maintenance plan. http://www.mlit.go.jp/river/basic_info/jigyo_keikaku/gaiyou/seibi/about.html (in Japanese)

Ministry of Land, Infrastructure, Transport and Tourism (2015). Flood Inundation Area Map/Flood Hazard Map. http://www.mlit.go.jp/river/bousai/main/saigai/tisiki/syozaiti/ (in Japanese)

Ministry of Land, Infrastructure, Transport and Tourism (2016). Disaster prevention action plan. http://www.mlit.go.jp/river/bousai/timeline/pdf/timeline_shishin.pdf (in Japanese)

Ministry of Land, Infrastructure, Transport and Tourism Kinki Regional Development Bureau (2013). Summary of Typhoon Flood No. 18 September 2013. https://www.kkr.mlit.go.jp/news/river/disaster/ol9a8v000001ffu8-att/ol9a8v000001ffvr.pdf (in Japanese)

Ministry of Land, Infrastructure, Transport and Tourism Kinki Regional Development Bureau Kizugawa-jouryu River Office (2017). Summary of floods caused by Typhoon 2017. https://www.kkr.mlit.go.jp/kizujyo/news/pdf/171106_typhoon21.pdf (in Japanese)

Ministry of Land, Infrastructure, Transport and Tourism Kinki Regional Development Bureau Yodogawa River Office (2014). Floods for typhoon 11 in 2014. https://www.kkr.mlit.go.jp/yodogawa/activity/comit/katsura-tisui/nb3uba0000003bez-att/20140813.pdf

Ministry of Land, Infrastructure, Transport and Tourism Kinki Regional Development Bureau (2019). Third Committee Material. https://www.kkr.mlit.go.jp/river/iinkaikatsudou/kensyoiinkai/ol9a8v000001jrzd-att/ol9a8v000001js26.pdf (in Japanese)

Nays2DFlood solver (ver.5.0) in iRIC. https://i-ric.org/en/solvers/nays2dflood/

Takagi, A., Sugiura, S., Mori, H. and Iwata, H. (2019). An analysis of resident evacuation behavior in the July 2018 heavy rainfall disaster — Case Study of Gifu Prefecture. *Journal of Natural Disaster Science*, 38: 133–151.

Uji City (2018). https://www.city.uji.kyoto.jp/0000010125.html (in Japanese)