Flood Hazard Mapping in Japan

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Abstract

This chapter aims to present the details of flood hazard mapping in Japan. The flood inundation mapping methodology used by Government of Japan is briefly described followed by the explanation on how the flood inundation modeled by MLIT and Prefectural Governments are used to prepare flood hazard maps by municipality/city governments. The uses of flood hazard maps are explained in details for the Kyoto City (as a case of Kyoto Prefecture) and the Omihachiman City (as a case of Shiga Prefecture) in Yodogawa River Basin. Finally, the institutional roles, legal frameworks, good practices and lessons learned about the flood hazard mapping are described in brief.

1. Introduction

1.1 Japan flood disaster statistics

The Infrastructure Development Institute of Japan and Japan River Association estimates about 49% of the population and 75% real estate in Japan are located in alluvial plains exposed to flooding risk [1]. The annual damage amount caused by water-related disasters in Japan from 1966 to 2010 is shown in **Figure 1**. The total flood inundated area was in the range of 100-200 thousand ha during 1966-1985. It shows a declining trend from 1982 onwards as a result of several years of flood control efforts. The annual flood inundated area (mostly with built or residential areas) was slightly above 50 thousand hectares (ha) in 1977. It has decreased over time as a result of various flood damage prevention systems such as widened channels and embankments, detention basins, floodways, and dam, etc. However, the density of property damage (the amount of damaged general assets) in inundated areas shows an increasing trend. The primary reasons are the continued population and general assets growth and increased urbanization-suburbanization in flood hazard areas. To avoid future flood damages in various forms, it is essential to understand the drivers of the flood risk and prevent anticipated damages by planning flood management strategies in advance.
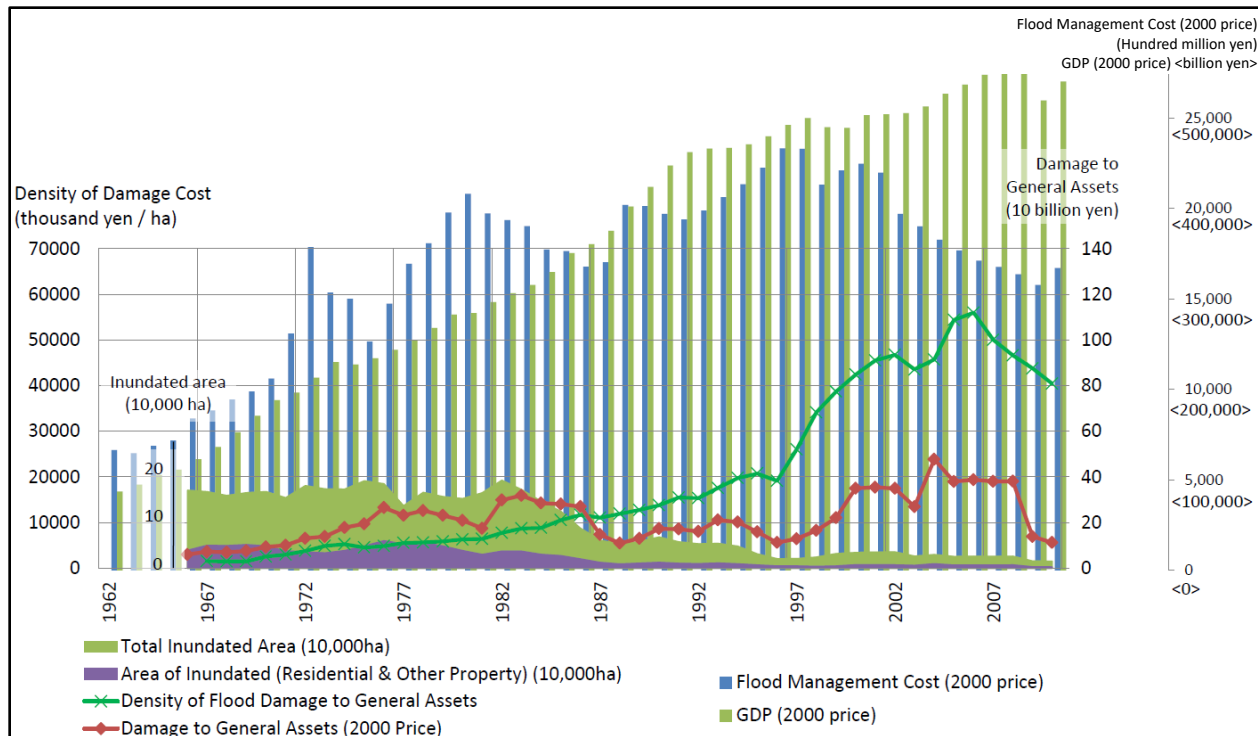
Figure 1 The annual damage caused by water-related disasters in Japan (adapted from [2])

1.2 Purpose of flood hazard mapping

For planning efficient flood management strategies in advance it is important to understand the flood risk. The flood risk is a function of flood hazard (the possibility of extreme flood event), exposure (the population and general assets in flood inundation areas), and vulnerability (the susceptibility of the exposed population and general infrastructure to flood hazard) [3]. The flood hazard in this chapter is defined as the possibility of flood inundation with different scenarios. The flood hazard map is a basis for understanding the exposure and vulnerability components of the flood risk. It provides the spatial information of flood inundation area, inundation depth and duration in a geographical region against the various scenarios of extreme rainfall events and determines the exposure of population, economic assets in the area likely to experience the damage. It serves as a reference tool for decision making, planning and implementation of flood preparedness and management strategies [4]. The flood hazard map is useful for the following purpose:

- To get advanced insights into the likelihood of the future flood events, exposed population, and ability to cope up with the event
- To inform residents about the probability of inundation in advance and raise their awareness
- To design guidelines for residents on how to act during a flood emergency
- To design evidence-based flood evacuation plans and search and rescue operations during a flooding event mainly useful for municipalities

- To estimate expected damages by flood in different areas
- To develop flood management plans and guidelines for infrastructure planning and future investments, etc.

The details of flood hazard mapping in Japan is explained in the following section.

2. Flood Hazard Mapping in Japan

2.1 Methods to develop flood hazard map

In Japan, flood hazard maps are mainly prepared by the Ministry of Land, Infrastructure, and Transport (MLIT) and Prefectural governments (local municipalities) using inundation information. The steps being currently used by MLIT to prepare flood hazard maps in Japan are given in the following sub-sections.

2.1.1 Flood inundation model: Shallow Water Equations

MLIT [5] uses the following shallow water equations (SWE) for the simulation of flood inundations areas:

$$\gamma\frac{\partial Q_x}{\partial t}+\frac{\partial}{\partial x}\left(\gamma\frac{Q_x^2}{h}\right)+\frac{\partial}{\partial y}\left(\gamma\frac{Q_x Q_y}{h}\right)+g\gamma h\frac{\partial(h+z_b)}{\partial x}+g\gamma n^2\frac{Q_x\sqrt{Q_x^2+Q_y^2}}{h^{7/3}}+\frac{1}{2}C_D'(1-\gamma)\frac{Q_x\sqrt{Q_x^2+Q_y^2}}{h}=0$$

$$\gamma\frac{\partial Q_y}{\partial t}+\frac{\partial}{\partial x}\left(\gamma\frac{Q_x Q_y}{h}\right)+\frac{\partial}{\partial y}\left(\gamma\frac{Q_y^2}{h}\right)+g\gamma h\frac{\partial(h+z_b)}{\partial y}+g\gamma n^2\frac{Q_y\sqrt{Q_x^2+Q_y^2}}{h^{7/3}}+\frac{1}{2}C_D'(1-\gamma)\frac{Q_y\sqrt{Q_x^2+Q_y^2}}{h}=0$$

$$\frac{\partial h}{\partial t}+\frac{\partial(\gamma Q_x)}{\partial x}+\frac{\partial(\gamma Q_y)}{\partial y}=q$$

where, Q_x, Q_y are the discharges per unit width in x and y directions, h the water depth, z_b the bed elevation, γ the porosity, q the rainfall, inundation from the sewerage, etc., n the roughness coefficient according to the land use, C_D the drag coefficient. The spatial resolution (grid size) for the model simulation of the Yodogawa River Basin is 25 m x 25 m.

2.1.2 Levee breach conditions

The amount of the flow overtopped from the river is estimated using modified Honma's overflow formula (as used in Manual for Economic Evaluation for Flood Control Investment, 2005, MLIT) [6].

a. **Honma's front-overflow formula:**

For complete overflow (for $h_2/h_1 < 2/3$),

$$Q_0 = 0.35 \ h_1 \sqrt{2gh_1} \ B$$

For submerged overflow (for $h_2/h_1 \geq 2/3$),

$$Q_0 = 0.91 \ h_2 \sqrt{2g \ (h_1 - h_2)} \ B$$

where Q is overflow discharge through structure and h_1, and h_2 are the water depth measured from the bed height of a breached levee.

b. Honma's side-overflow formula:

Inundation discharge (Q) following a levee breach is given by:

For I > 1/1580,

$$\frac{Q}{Q_0} = \left(0.14 + 0.19 \times \log_{10}\left(\frac{1}{I}\right)\right) \times \cos\left(48 - 15 \times log_{10}\left(\frac{1}{I}\right)\right)$$

For 1/1580 ≥ I > 1/33600,

$$\frac{Q}{Q_0} = \left(0.14 + 0.19 \times \log_{10}\left(\frac{1}{I}\right)\right)$$

For 1/33600 ≥ I,

$$\frac{Q}{Q_0} = 1$$

where Q is inundation flow, Q_0 is flow volume calculated by Honma's formula, I is bed slope of a river, and B is the width of the crest. The unit of "cos" in the parenthesis is "degree."

2.1.3 An approach to estimate maximum inundation depths

The steps to prepare flow inundation area map using SWE and levee breach conditions are shown in **Figure 2**. In step 1, it is assumed that the levee breach has occurred at two or more locations simultaneously. It is assumed that inundation starts at or above the designed high water level in the river. The levee breach is assumed at a point if the water level in the river is greater than the designed high water level of the river. In step 2, inundation depths are simulated for individual levee breach points. Step 3 overlays the inundation maps (for two or more levee breaches) obtained in step 2 to estimate maximum inundation depths. Finally, in step 4, the maximum inundation depth maps are distributed to local governments, and other stakeholders, etc. The MLIT disseminate flood inundation maps through its 'Hazard Map Portal Site' at
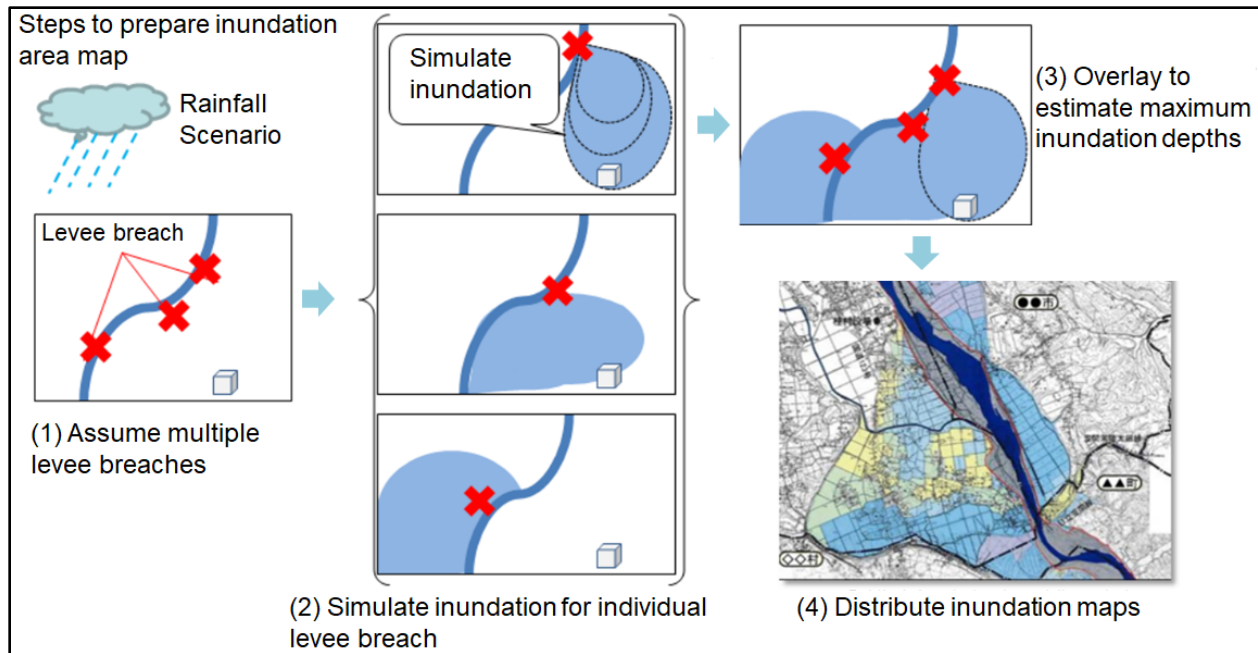https://disaportal.gsi.go.jp/

Figure 2 Steps to prepare the inundation area map (Source: MLIT [7])

2.2 Scenarios of external force to develop flood hazard map

According to the Flood Fighting Act (FFA) amended in 2014 the river administrators, MLIT and prefectural governments should design the area that might be inundated during the flooding events. The act specifies that two rainfall scenarios should be considered as inputs to simulate flood hazard (inundation area) maps. The first scenario is to use the design-rainfall used for the river works as input to simulate flood inundation. In case of the Yodogawa River, the design rainfall is assumed equivalent to 200-year return period (261 mm in 24 hours) while the upstream tributaries assume comparatively smaller return periods (150-years): for the Uji River (164 mm in 9 hours), the Kizu River (253 mm in 12 hours) and the Katsura River (247 mm in 12 hours).

The second scenario is to use the largest-scale (worst case) rainfall as input to simulate flood inundation. Based on rainfall patterns, the whole Japan is divided into 15 regions, and Depth-Area-Duration (DAD) analysis is conducted using recorded maximum rainfall in each region. **Figure 3** shows the DAD relationship for the Kinki region. The average basin rainfall can be estimated from DAD analysis and typically exceed or equivalent to 1000-year return period. If the historical maximum rainfall observed is less than the rainfall corresponding to the exceedance probability of 1/1,000 (360 mm/24 hr), then the rainfall corresponding to that exceedance probability is used for the simulation as maximum rainfall in the worst-case scenario. The historical maximum rainfall observed in the Hirakata station (Yodogawa River Basin) is 314 mm in 24 hrs which is less than 360mm in 24 hrs. Hence the rainfall by DAD analysis for the Yodogawa River Basin is assumed to be 360 mm in 24 hours for the simulation, whereas for its major tributaries: for the Uji River is 356 mm in 9 hours; for the Kizu River is 358 mm in 12 hours; and for the Katsura River is 341 mm in 12 hours.
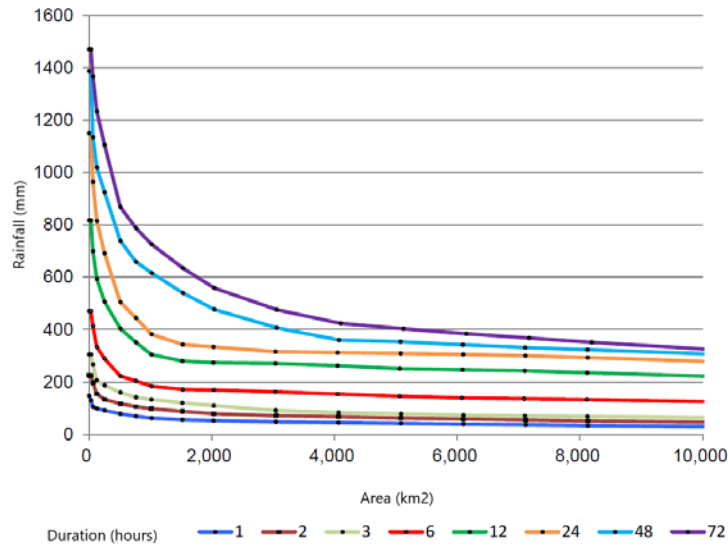
5

Figure 3. DAD analysis for the largest-scale scenario (e.g., Kinki Region). [8]

The inundation simulation maps are prepared by MLIT using the second scenario in combination with steps in subsection 2.1. The prefectural government may use the flood inundation map (25m X 25m) prepared by MLIT to plan mitigation activities during flood events for decision making, planning, and implementation of flood management strategies. However, the prefectural governments can also develop their own inundation models using different tools. For example, the Shiga Prefectural government uses own model for flood inundation simulation (50m X 50m). In addition to MLIT and prefectural governments' flood simulation models, a list of commonly used flood inundation models in Japan is given in **Appendix A**.

3.   Flood Hazard Map of the Yodogawa River Basin

3.1 Location

The Yodogawa River Basin located in the central part of Japan is shown in **Figure 4.** The length of the Yodogawa River is 75 km. It is the seventh largest river basin in Japan with a catchment area of 8,240 km^2 [9]. Flowing south out of Lake Biwa, the largest lake in Japan, first as the Seta River and then the Uji River, it merges the Kizu River and the Katsura River near the border between Kyoto and Osaka Prefectures. The Yodogawa River runs through the heartland of the Kinki region and flows into the Osaka Bay. The Yodogawa River basin consists of six sub-catchments, which are the Lake Biwa basin (3,802 km^2), the Uji River basin (506 km^2), the Kizu River basin (1,647km^2), the Katsura River basin (1,152 km^2), the lower Yodogawa River basin (521 km^2) and the Kanzaki River basin (612 km^2). It extends over six prefectures namely Shiga, Kyoto, Osaka, Hyogo, Nara, and Mie [10].
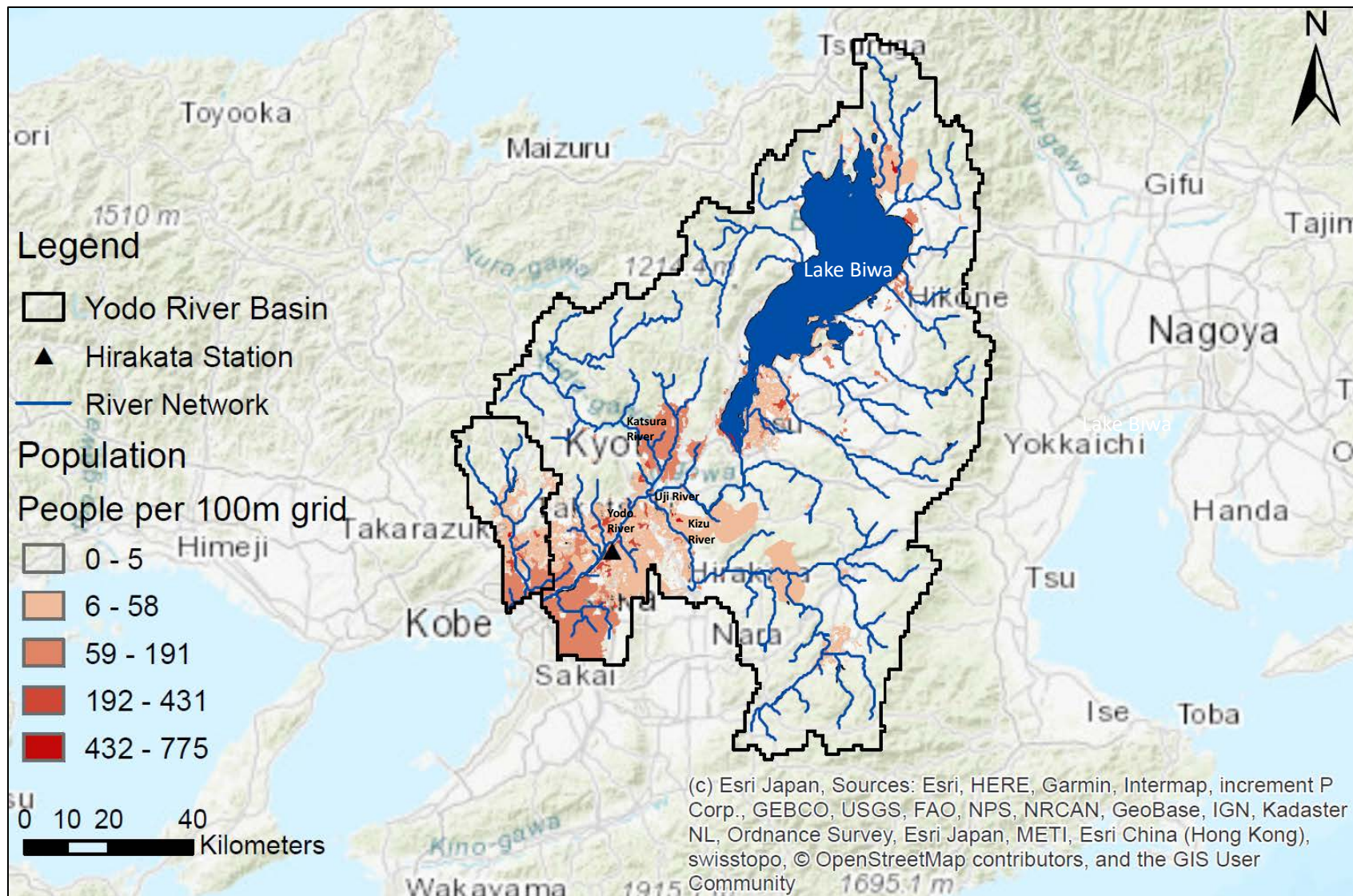
Figure 4 Location of Yodogawa River basin in Japan (The figure is prepared in ArcMap 10.6.1 using data from the Geospatial Information Authority of Japan (GSI), HydroSHEDS, WorldPop [11] and ArcGIS online).
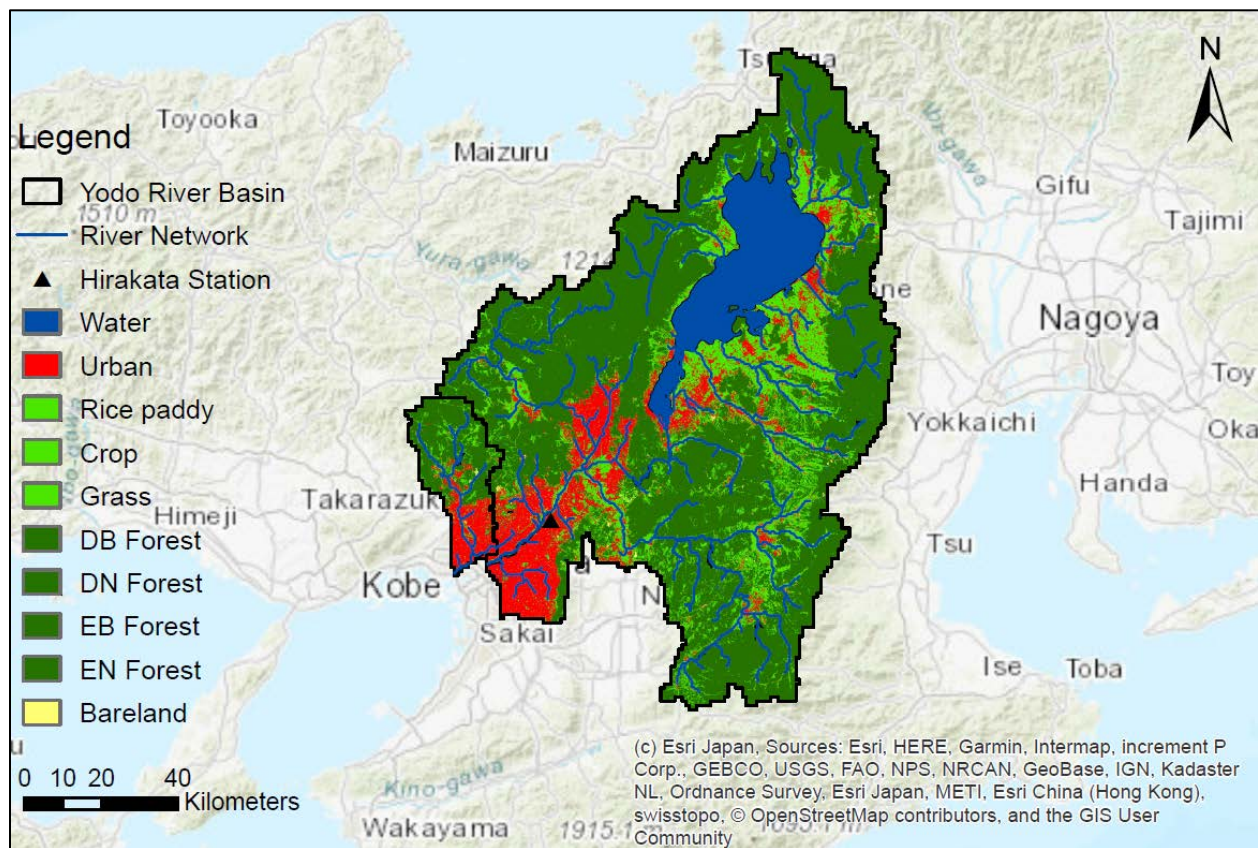
Figure 5 Land use map of the Yodogawa River Basin (The figure is prepared in ArcMap 10.6.1 using data from JAXA EORC [12] and Geospatial Information Authority of Japan (GSI), HydroSHEDS, and ArcGIS online)

City areas spread throughout the basin as shown in **Figure 5**. Metropolitan areas such as Osaka, Kyoto, and Otsu are located along the rivers. The population in the basin is about 9.30 million in 2015 [11,13]. In the lower Yodogawa River basin, most of the highly populated urban developments are in areas lower than the river water level. In Osaka City, it is estimated that 94.9% of the total metropolitan area is in the flood-prone area [10].

3.2 Hydrologic characteristics

The mean annual rainfall of the Yodogawa River Basin is 1,600 mm. The rainfall in the basin is widely distributed in time and space. The annual precipitation of the Lake Biwa sub-basin, the Katsura River sub-basin, the Kizu River sub-basin, and the lower Yodogawa River sub-basin are about 1,880 mm, 1,640mm, 1,590mm, and 1,400mm, respectively [10]. The major flood events in the Yodogawa River Basin are shown in **Figure 6.** During 1970 -2018, 1972, 1982 and 2013 the water level at Hirakata station (location shown in Figure 4 and 5) in the basin exceeded the 'Damage attention water level' and caused flooding in the basin.
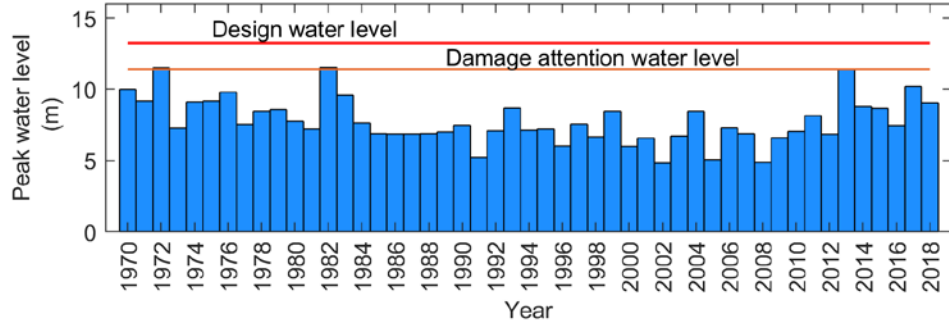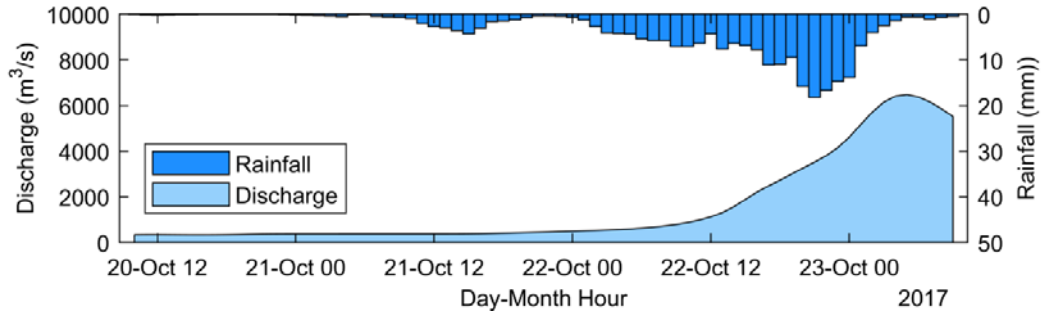
(a) Observed peak water level at Hirakata Station [14]
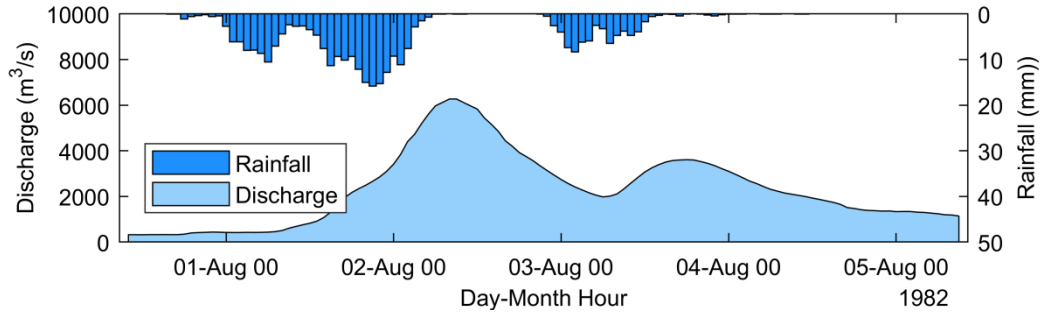
(b) Hydrograph: Typhoon No. 10 in 1982
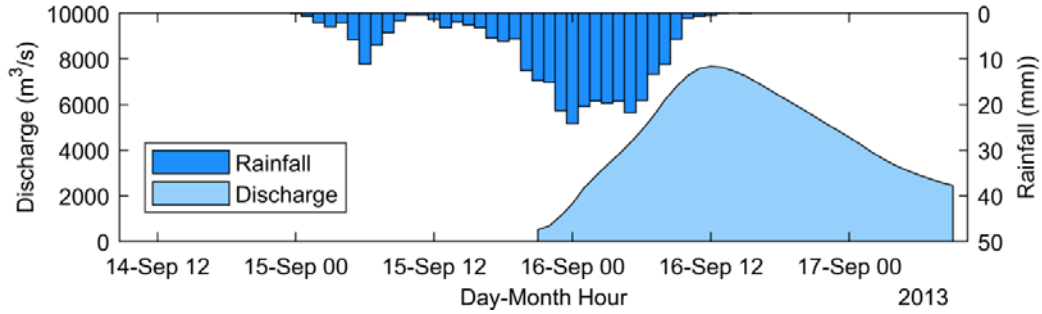
(c) Hydrograph: Typhoon No. 18 in 2013

(d) Hydrograph: Typhoon No. 21 in 2017

Figure 6 Major flood events in the Yodogawa River Basin (Rainfall: Average rainfall in the Upper Catchment area above Hirakata station; Discharge: Discharge recorded at Hirakata station. Discharge during 2017 is a temporary estimate) [15].

3.3 Flood hazard map

The simulated flood hazard map of Yodogawa River Basin with 25 m X 25 m resolution is shown in **Figure 7**. The second scenario of the external force, i.e., the amount of rainfall 360 mm in 24 hours is used to simulate flood inundation depth. The estimated inundation areas cover approximately 144 km^2 in Osaka prefecture and 121 km^2 in Kyoto prefecture where Osaka City and Kyoto City are major urban areas, respectively. The maximum inundation area is anticipated in Osaka City is about 62 km^2 with an average inundation depth 2.4 m ranging from 2.6 to 7.2 m. The maximum inundation depth of 8 m is anticipated in Takatsuki City in the Osaka prefecture. The model simulated about 40.9 km^2 inundated area in Kyoto City around Katsura River (and its major tributary Kamo River) and Uji River. The average inundation depth of 2.7m is anticipated in Kyoto City ranging from 1.9 to 7.4m.
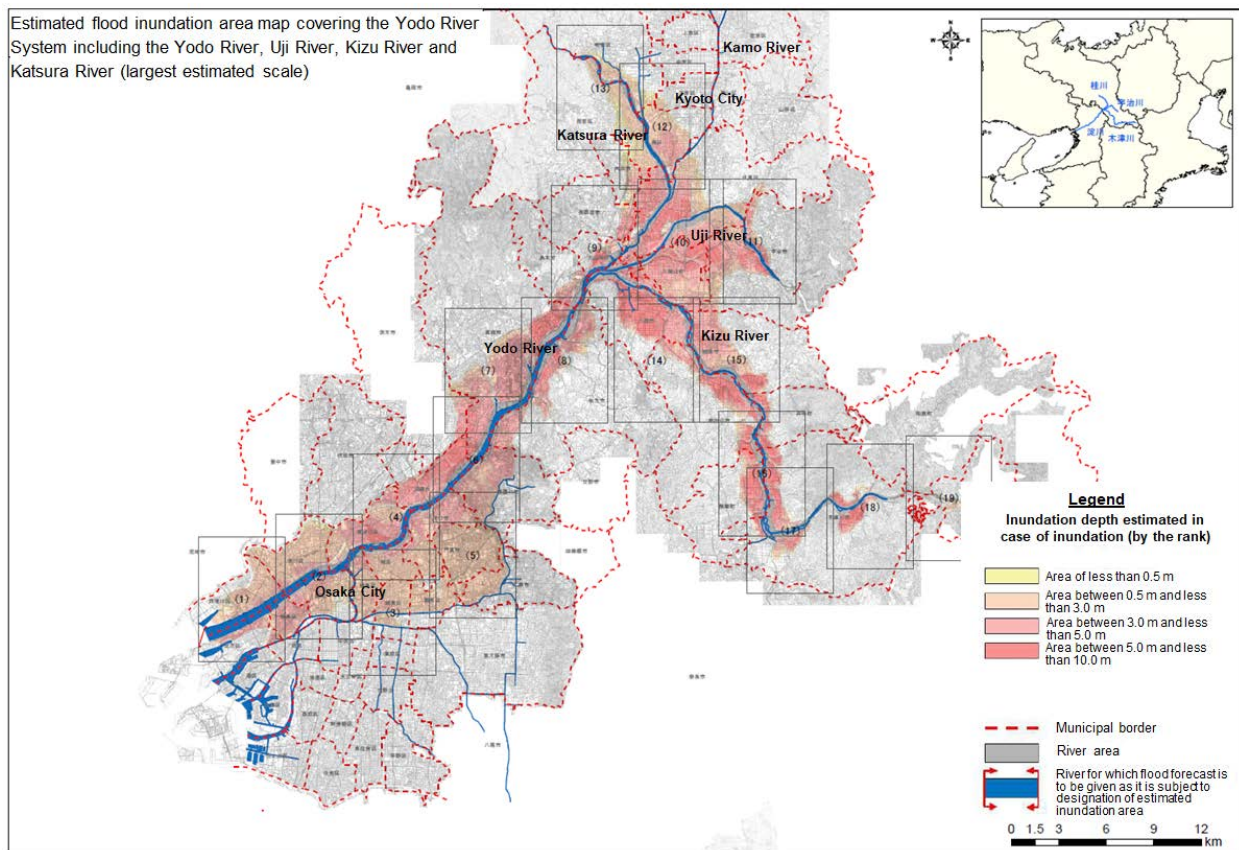

Figure 7 Estimated flood inundation area map of the largest estimated scale of the Yodogawa River Basin (Source: MLIT [16]). Authors have translated the important legend to English.

4. <u>Usage of Flood Hazard Maps</u>

Flood hazard maps prepared by MLIT are useful for the city and prefectural governments to design flood mitigation strategies as explained in the Introduction section. Following are the specific examples of usage of flood hazard maps.

4.1 Flood hazard mapping: Kyoto City in Kyoto Prefecture

Example of the flood inundation map (25m X 25m mesh size) of the largest estimate scale prepared by MLIT for the wards of Kyoto City is shown in **Figure 8.** The Prefectural and City Government use this map as a reference to design flood management strategies.
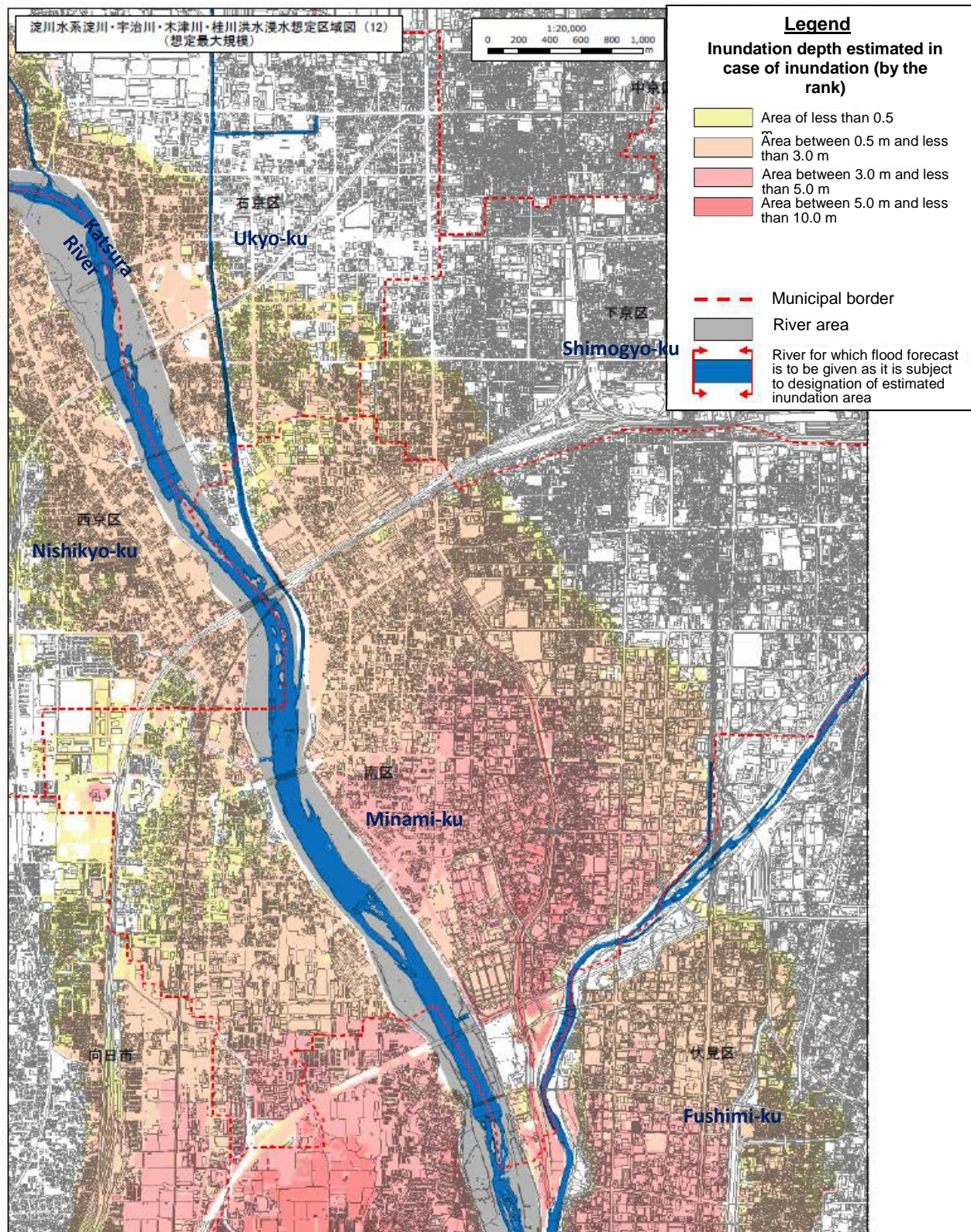
Figure 8 Estimated flood inundation area map of the largest estimated scale (zone 12 in Figure 7) for Kyoto City: Nishikyo-ku, Ukyo-ku, Shimogyo-ku, Minami-ku, & Fushimi-ku (MLIT [16]). Authors have translated the important legend to English.
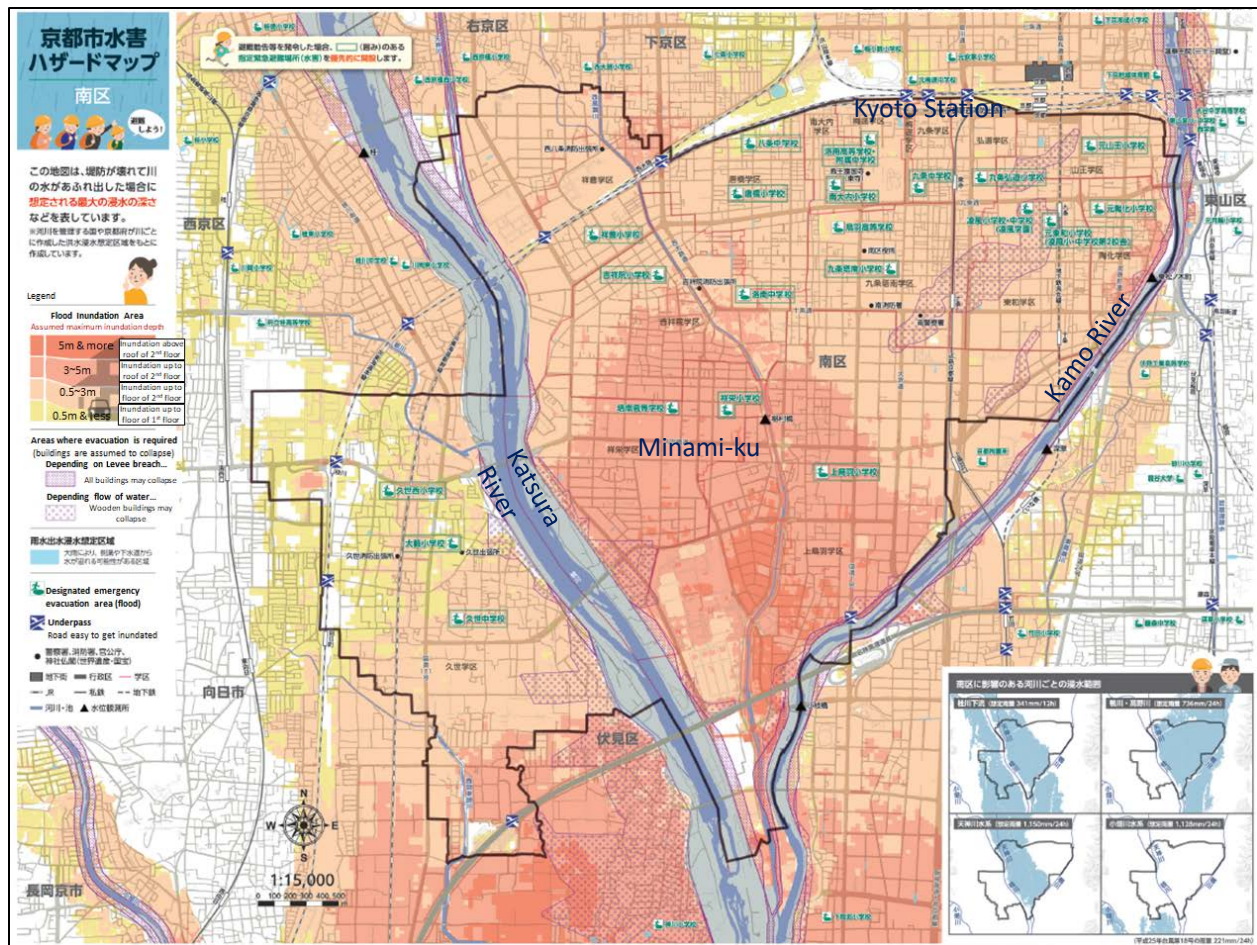
Figure 9 Flood hazard map of Kyoto City, Minami-ku (at the largest estimated scale) by MLIT downloaded from Kyoto City Government Website [16,17]. Authors have translated the important legend to English.

The MLIT is responsible for the inundation map of the Katsura River and Kyoto Prefectural government is responsible for the inundation map of the Kamo River. The inundation depths obtained from the MLIT and Kyoto Prefecture Government is used in **Figure 9**. The flood hazard map (largest estimated scale) for the Minami-ku ward of the Kyoto City prepared by Kyoto City Government is shown in **Figure 9**. The major bullet point information shown on the map is summarized as: This map shows the maximum depth of flooding with levee breach assumption. It is based on the flood inundation map created by river management authority (Yodogawa River Bureau – MLIT, Kyoto Prefectural Government). The legend shows the maximum inundation depth assumed. 0.5 m (inundation in the first floor), 0.5-3.0m (flooding to the floor of the second floor), 3.0-5.0 m (Inundation to the roof of the second floor), 5.0m (the flood water level above the second floor). It also shows the areas where buildings are expected to collapse, the sewers where water may overflow, and temporary evacuation shelters during the flooding event, etc.

With reference to the flood hazard map shown in **Figure 9**, Kyoto City government has prepared the easy to understand evacuation needs and actions as shown in **Figure 10**. Information on when-, why-, how-, and where- to evacuate is designed using the flood inundation maps.
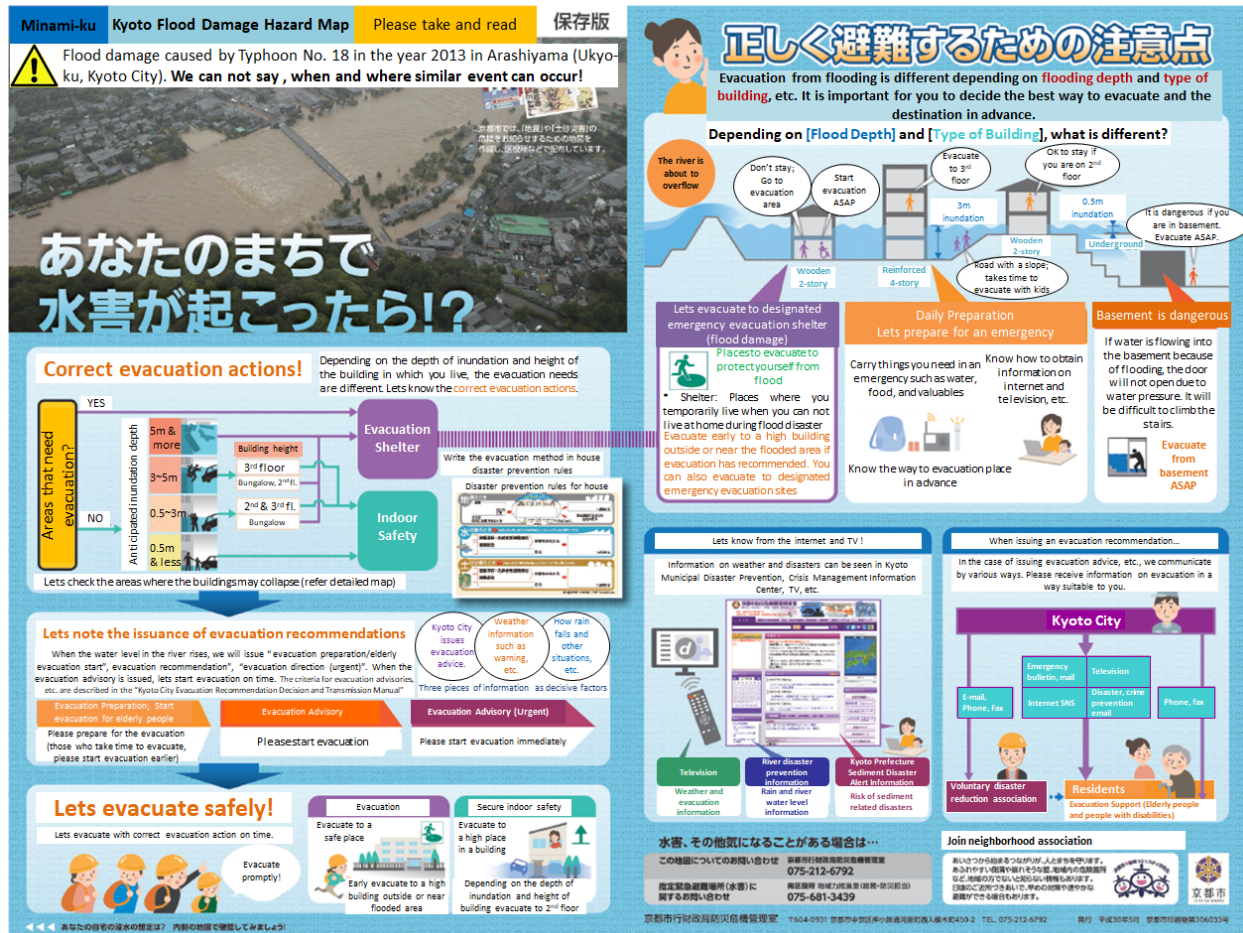

Figure 10 Basic information added to the flood hazard map for safe evacuation by Kyoto City Government [17]. Authors have translated the Japanese version to the English for an easy understanding.

4.2 Flood hazard mapping: Omihachiman City in Shiga Prefecture

The Shiga Prefectural Government has developed a numerical flood simulation model to simulate the flood inundation in 50m X 50m mesh size [18,19]. The model predicts rainfall-runoff, channel flows, overland flow and plain flow considering topping or breach processes. The numerical model details are given in [18]. For inundation simulation, the rainfall 10, 30, 50, 100, 200, 500, and 1000 years return periods assumed uniform over the study area in combination to the three types of levee breach conditions. **Figure 11** (b, c, d) shows the inundation simulation for the Omihachiman City in Shiga prefecture for rainfall input as 10, 100, and 200 years return period. The probability of the inundation above the ground floor (inundation depth > 0.5m) on the flood hazard risk map for the Shiga Prefecture is shown in **Figure 12**.
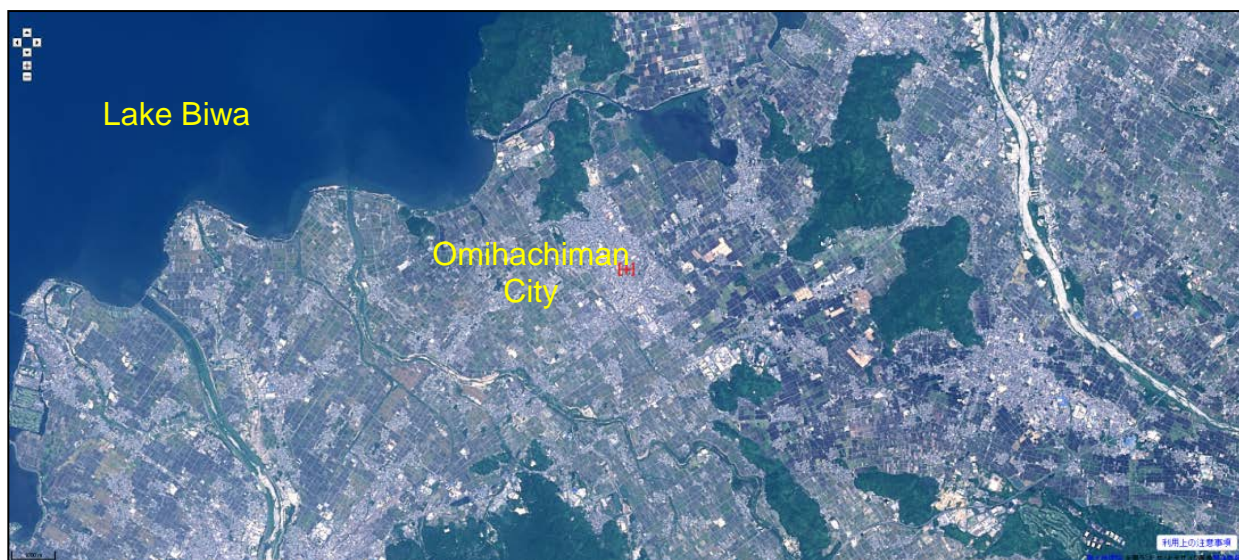
(a) Aerial photograph of Omihachiman City in Shiga Prefecture
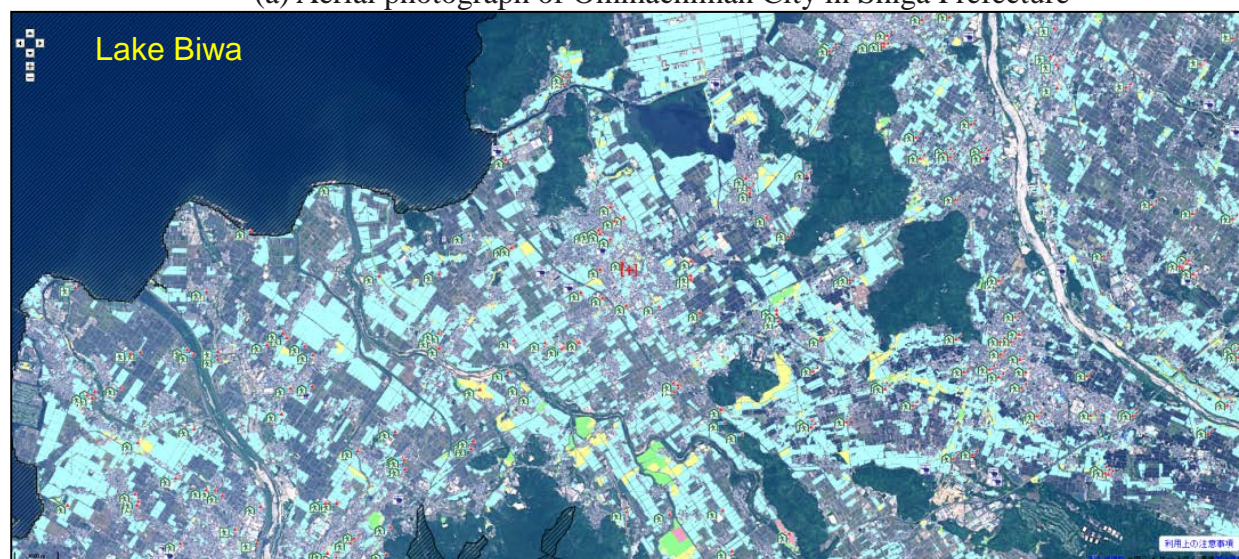
(b) Prob. of maximum inundation depth (50 mm/hr rain; once in 10 years)

Legend
Inundation depth

Up to second floor

5.0m
4.0m
3.0m
2.0m
1.0m
0.5m

Up to first floor

Emergency shelter, etc.

Disaster helipad

Figure 11 Flood hazard map for Omihachiman City in Shiga prefecture (Source: Prepared by authors using screenshots from Shiga Prefectural Government Website http://shiga-bousai.jp)

(c) Prob. of maximum inundation depth (109 mm/hr rain; once in 100 years)
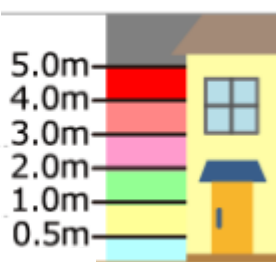

(d) Prob. of maximum inundation depth (131 mm/hr rain; once in 200 years)

Legend
Inundation depth

Up to second floor
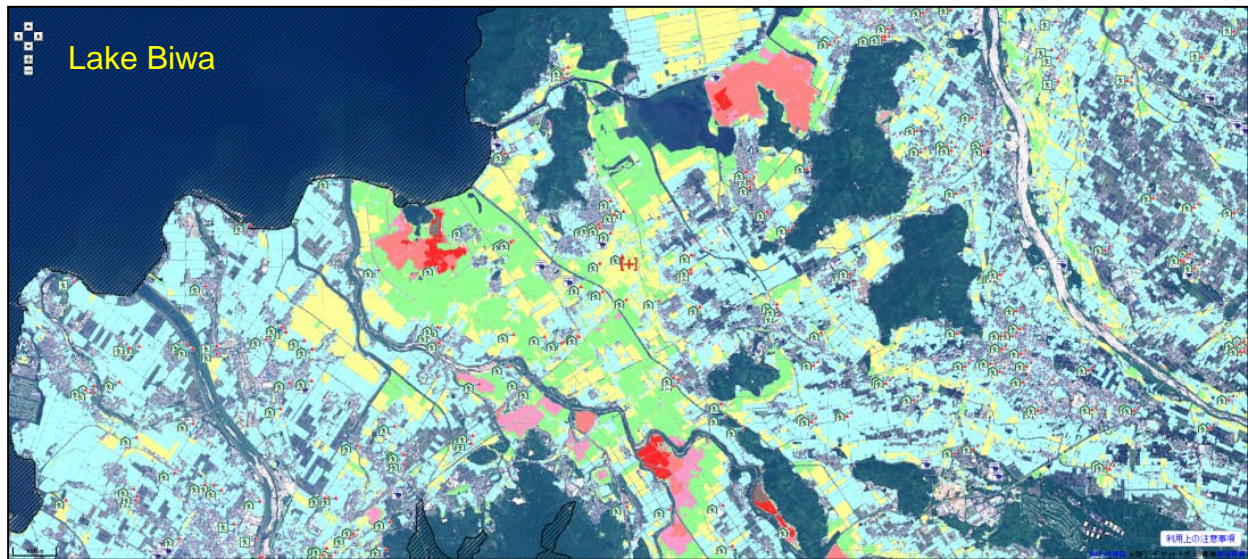
Up to first floor

5.0m
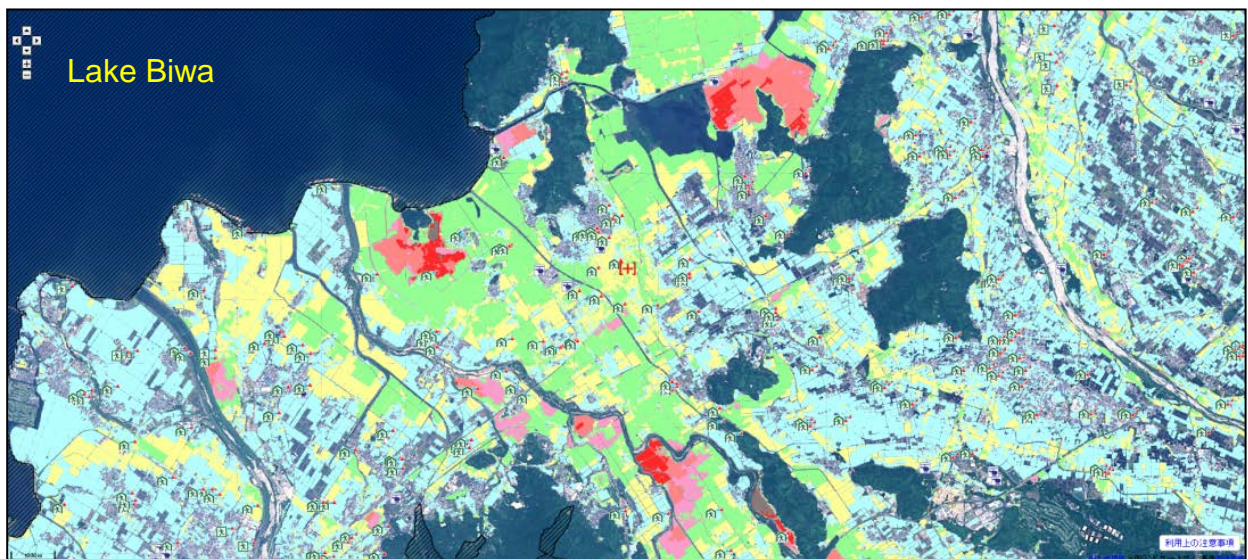4.0m
3.0m
2.0m
1.0m
0.5m

Emergency shelter

Disaster helipad

Figure 11 Flood hazard map for Omihachiman City in Shiga prefecture (Source: Prepared by authors using screenshots from Shiga Prefectural Government Website http://shiga-bousai.jp)
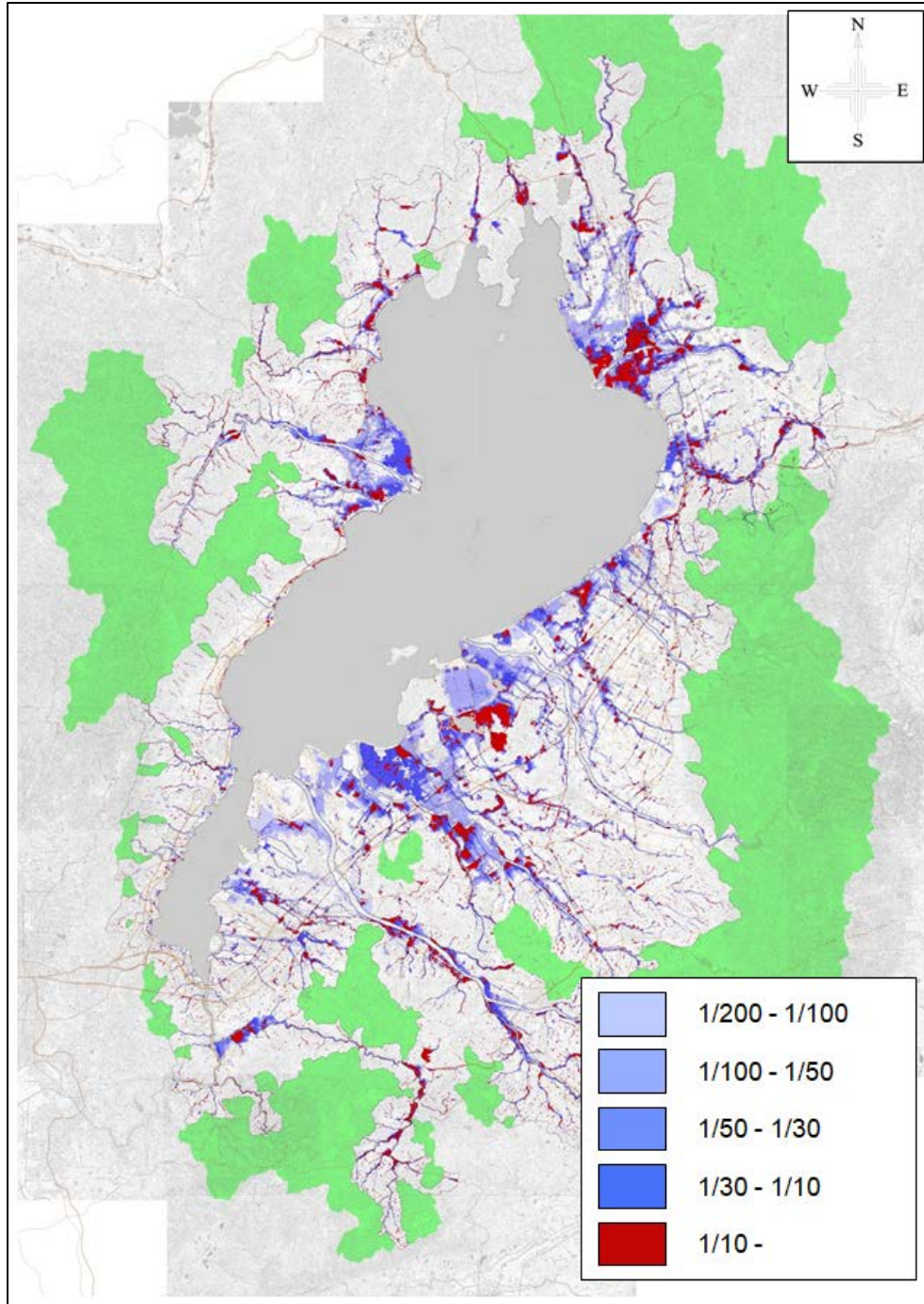
Figure 12 Probability of the inundation above the ground floor (inundation depth > 0.5m) on the flood hazard risk map for the Shiga Prefecture (adapted from [19]).

The flood inundation map with the 100-year return period is used to prepare the flood hazard maps. The example of a flood hazard map for the Omihachiman City in Shiga Prefecture is shown in **Figure 13**.

Figure 13 Flood hazard map for the Omihachiman City in Shiga Prefecture. The major legends are shown in English. (Map prepared using the 100-year return period) Source: [20].

5. Institutional and Legal Frameworks for Flood Hazard Maps

5.1 Institutional and legal frameworks

The scope of flood hazard mapping falls under the MLIT River Bureau, Prefectural Governments, and Municipal (City) Governments activities. According to the Flood Control Act (FCA) amended in 2014 [21], the Minister of MLIT and prefectural governments should design the area that might be inundated during a flooding event (Article 14) as shown in **Figures 7, 8, 11,** and **12**. The municipal (City) governments are responsible for the design and dissemination of information in the form of flood hazard maps to residents (Article 15). The examples are shown in **Figure 9** and **13**.

5.2 Dissemination of flood hazard map

Flood hazard maps are widely disseminated in various ways (mainly, pamphlets, online publishing). The MLIT disseminate flood inundation maps through its 'Hazard Map Portal Site' at

https://disaportal.gsi.go.jp/

The flood inundation maps for the Yodogawa River Basin are available at the following website:

http://www.kkr.mlit.go.jp/yodogawa/activity/maintenance/possess/sotei/index.html

Local municipal/prefectural governments' show the maps and evacuation area on their website homepage. Kyoto City provides the Kyoto City flood hazard maps on the following website:

http://www.city.kyoto.lg.jp/gyozai/page/0000237021.html.

The Shiga Prefectural Government provides flood hazard maps on the following website:

http://shiga-bousai.jp/dmap/map/index?l=M_r_k_risk_map&z=&lon=&lat=

6. Good Practices and Lesson Learned

6.1 Good practices

The flood hazard map (or flood hazard risk maps) developed by the city is used for land use and building regulations. For example, the areas in Shiga Prefecture whose estimated inundation depth is greater than 0.5m with ten-year flood return period are prohibited from inclusion in the urbanized promotion area stipulated by the City Planning Law [19]. Also, the Prefectural Flood Management Ordinance stipulates that the real-estate agencies must inform their customers appropriate flood risk information before making a real estate transaction.

The latest hazard mapping is done at a higher spatial resolution (25 m X 25 m mesh grid) with multiple rainfall scenarios and levee breach conditions. In addition to the flood inundation, inundation duration time and house collapse hazard zones are proposed in latest inundation area estimates which are useful for designing the flood hazard map (particularly identify the areas where early evacuation is necessary and location of evacuation shelters).

The information on evacuation routes and shelters is disseminated in advance by using easy to understand hazard maps. The information is also made available through websites and mobile applications.

Depending on the depth of water and type of building, area-specific modes of evacuation, i.e., horizontal and vertical evacuation needs are explained in the flood hazard map.

6.2 Lesson learned, gaps/challenges:

The flood hazard maps are a vital tool for future flood preparedness. The Mabicho town of Kurashiki City in Okayama Prefecture experienced the worst flood on July 7, 2018. The flood hazard map designed by Kurashiki Municipal Government before the flood disasters show a good agreement with the areas and depths of the flood occurred on July 7, 2018 [22].

There is a need to increase people's awareness about flood hazard map. It has been found that the people who have not seen the flood hazard map take more time to evacuate (about 1 hour more [23]) than the people who have seen flood hazard map in advance. Hence it is important to increase the individual's awareness of flood hazard-prone areas and evacuation options. In addition to increasing individual awareness, the improvement in reliability of flood hazard maps is essential.

People moved to a new city and prefectures are often unaware of the historical flood information in the region. Hence, the real-estate agencies should inform their customers about appropriate flood risk information prior to the transaction.

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Appendix A

<u>Examples of software used for flood inundation simulation in Japan</u>

1. Rainfall-Runoff Inundation (RRI)

The RRI model is a two-dimensional model capable of simulation the runoff and flood inundation using rainfall, digital elevation model (DEM), land cover, and river cross section [24,25].

Website: http://www.icharm.pwri.go.jp/research/rri/index.html

2. Nays 2D Flood

Nays 2D Flood is a two-dimensional flood flow simulation model [26].

Website: https://i-ric.org/en/download/

3. DioVISTA

DioVISTA flood simulator developed by Hitachi Ltd. [27]
Website: http://www.hitachi-power-solutions.com/en/products/product12/p028.html