Development of User-Friendly Hazard Maps and Information Based on Maximum Flood Inundation

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ABSTRACT

Severe water-related disasters occur in Japan on an almost yearly basis due to typhoons and frontal rains; these events are often characterized by evacuation difficulties. Main purpose and final goal of this study were to develop a user-friendly hazard map that give high impacts on the local people who underestimate the flood hazard risks in their town. To overcome the evacuation problems in Japan, we proposed the distribution of high-risk zone information determined using probable maximum flood inundation data. A rainfall runoff and two-dimension flood inundation models were applied to the Toyama City under the several rainfall scenarios in the basins and several embankment failure points along the rivers to compute the probable maximum flood inundation situations. The simulations produced maximum flood inundation depths exceeding 3.3 m in several areas, which we therefore designated as high-risk zones. Finally, we proposed new hazard maps based on probable maximum flood inundation that were designed for easy use by local people.

INTRODUCTION

Severe water-related disasters occur in Japan on an almost yearly basis due to typhoons and frontal rains; these events are often characterized by evacuation difficulties. In our previous study (Kure et al., 2020), we conducted a questionnaire survey among local people in Toyama Prefecture, Japan to evaluate their awareness of disaster-related information. As a result of this analysis, we determined that many people do not fully understand locally distributed disaster information. Therefore, to overcome the evacuation problems investigated in the previous study,

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we proposed the distribution of high-risk zone information based on probable maximum flood inundation data.

STUDY AREA

The target area for this study was Toyama City, near the Jinzu and Jouganji Rivers in Toyama Prefecture, Japan (**Figure 1**). The Jinzu River is 120 km in length and originates from Kaoredake, Gifu Prefecture (1,626 m a.s.l.), with a catchment area of 2,720 km^2. The Jouganji River is 56 km in length and originates from Kitanomatadake, Toyama Prefecture (2,661 m a.s.l.), with a catchment area of 368 km^2. The Jouganji River is the steepest river in Japan, with river bed gradients of about 1/30 in the mountains and about 1/100 on the flood plain. The Jinzu River is also steep, with river bed gradients of about 1/20 to 1/150 upstream, 1/150 to 1/250 midstream, and 1/250 to 0 downstream. It is important to consider these steep river segments when evaluating flood hazard, because high-speed river flows can cause levee erosion and scouring.

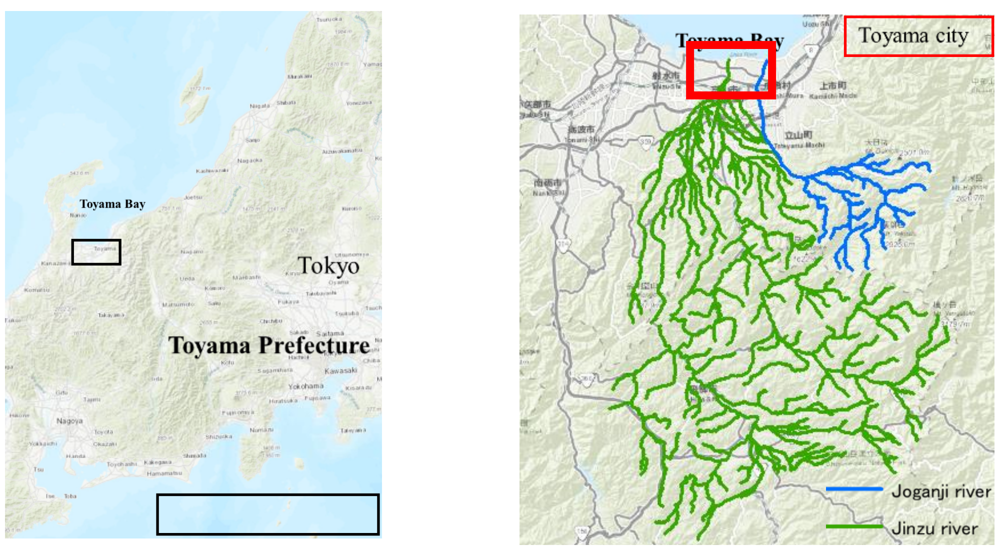

Figure 1. Locations of Toyama Prefecture (left) and the study area (right).

METHODOLOGY

Flood inundation model

The flood inundation model consisted of a hydrodynamic module for rivers and canal networks, and a flood inundation module for the floodplain. This model has been applied to several basins in Japan, as well as to Jakarta, Indonesia (Kure et al., 2008; Moe et al., 2017; Priyambodoho et al., 2017).

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Flood routes for rivers and canal networks were calculated using a continuous equation (1) and the Saint-Venant momentum equation for unsteady flow (2):

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_l \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial \left(\alpha \frac{Q^2}{A} \right)}{\partial x} + gA\frac{\partial h}{\partial x} + \frac{n^2 gQ|Q|}{AR^{4/3}} = 0 \tag{2}$$

where Q is discharge (m^3 s^{-1}), A is the cross-sectional area (m^2), q_l is lateral inflow or outflow distributed along the x-axis of the watercourse (m^2 s^{-1}), n is Manning's roughness coefficient, α is the momentum distribution coefficient, g is acceleration due to gravity (m s^{-2}), R is the hydraulic radius (m), and h is the water level (m).

Unsteady two-dimensional flow equations, consisting of the following continuity equation and momentum equations, were solved numerically for the flood inundation simulation of the floodplains. The details of this numerical simulation have been described previously (Moe et al., 2017).

$$\frac{\partial h}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = 0 \tag{3}$$

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial x}\left(\frac{p^2}{h} \right) + \frac{\partial}{\partial y}\left(\frac{pq}{h} \right) + gh\frac{\partial \zeta}{\partial x} + \frac{gp\sqrt{p^2 + q^2}}{C^2 - h^2} - \frac{1}{\rho_w}\left[\frac{\partial}{\partial x}(h\tau_{xx}) + \frac{\partial}{\partial y}(h\tau_{xy}) \right] = 0 \tag{4}$$

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial y}\left(\frac{q^2}{h} \right) + \frac{\partial}{\partial x}\left(\frac{pq}{h} \right) + gh\frac{\partial \zeta}{\partial y} + \frac{gq\sqrt{p^2 + q^2}}{C^2 - h^2} - \frac{1}{\rho_w}\left[\frac{\partial}{\partial y}(h\tau_{yy}) + \frac{\partial}{\partial x}(h\tau_{xy}) \right] = 0 \tag{5}$$

where *C(x,y)* is the Chézy resistance (m$^{1/2}$ s^{-1}); ρ_w is the density of water (kg m^{-3}); ζ(x,y,t) is the water elevation (m); τ_{xx}, τ_{xy}, and τ_{yy} are the components of effective shear stress (kg m^{-1} s^{-2}); *p*(x,y,t) and *q*(x,y,t) are flux densities (m^3 s^{-1} m^{-1}) in the x- and y-directions, respectively; *h*(x,y,t) is the water depth (m), and *g* is acceleration due to gravity (m s^{-2}).

The Manning roughness coefficients of the river beds were set as 0.03–0.05 for different river sections; those of the land surface were set as 0.05 for all floodplains during calibration.

Dataset

Cross-sectional data for rivers in the target area were provided by the Toyama Office of Rivers and National Highways, Ministry of Land, Infrastructure, Transport and Tourism (MLIT). We

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used the J-FlowDir dataset (Yamazaki et al., 2018) to create a 30-m resolution digital elevation model (DEM); its accuracy was verified using a 5-m resolution DEM obtained from the Geospatial Information Authority of Japan, MLIT. Predicted high flows of the target rivers were obtained from open reports published by MLIT.

RESULTS

Flood inundation simulations were conducted for several scenarios. We performed a sensitivity analysis to evaluate whether the resolution of the 30-m DEM was sufficient for local flood hazard evaluation. Sample flood inundation simulation results obtained using DEMs with 30- and 5-m resolution are shown in **Figures 2** and **3**, respectively. The 5-m-resolution DEM yielded detailed inundation information for small-scale features, such as roads and paddy fields. However, the 30-m-resolution DEM also simulated inundation depth and flood flow velocity reasonably well; therefore, we decided to use the 30-m-resolution DEM in subsequent simulations due to its easy and rapid computation abilities.

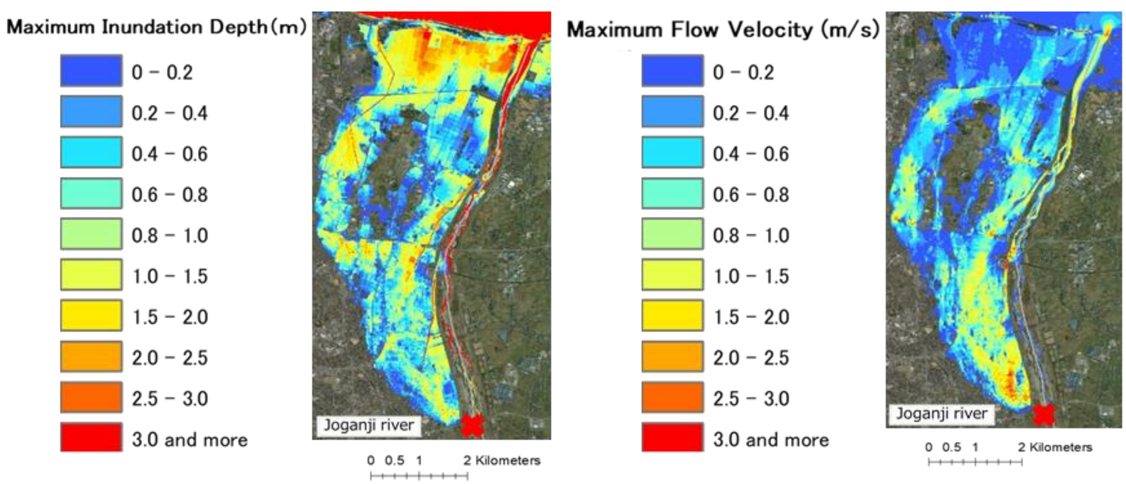

Figure 2. Maximum inundation depth (left) and flow velocity (right) simulation results obtained using a 30-m-resolution digital elevation model (DEM).

We produced a probable maximum flood inundation simulation based on historical data (Kure et al., 2016). The simulation results showed maximum inundation depths exceeding 3.3 m in several areas, which we considered as high-risk zones. These flood inundation simulation results can be visualized using several map types or virtual reality (VR) technology (**Figure 4**) to better understand flood hazards in target areas.

To evaluate the flood inundation simulation results, we proposed a new method for ranking flood risks based on flood inundation depth, flow velocity, and hydrodynamic forces. For example, **Figure 5** shows two-stage flood risk zoned identified using the proposed method. People in the

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high-risk zone (red) require early evacuation prior to a flood event, whereas those in the low-risk zone (blue) may safely remain in their houses, perhaps moving to the second or third floor. This new risk identification method was developed based on the LIFESim (US Army Corp., 2004) and Floris (Rijkswaterataat, 2016) models, and is designed to encourage people who may underestimate flood risk to accurately assess their own risk and prepare for early evacuation if necessary. In a future study, this classification scheme will be combined with a hazard map, developed from the simulations performed in this study, to produce a new and user-friendly hazard map.

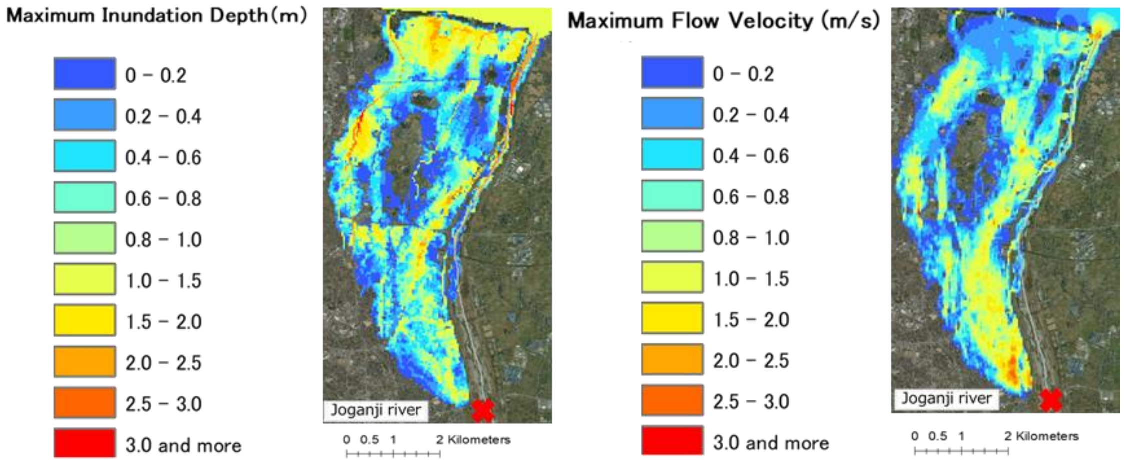

Figure 3. Maximum inundation depth (left) and flow velocity (right) simulation results obtained using a 5-m-resolution DEM.

Figure 4. Virtual reality (VR) technology used to visualize flood inundation scenarios (under development).

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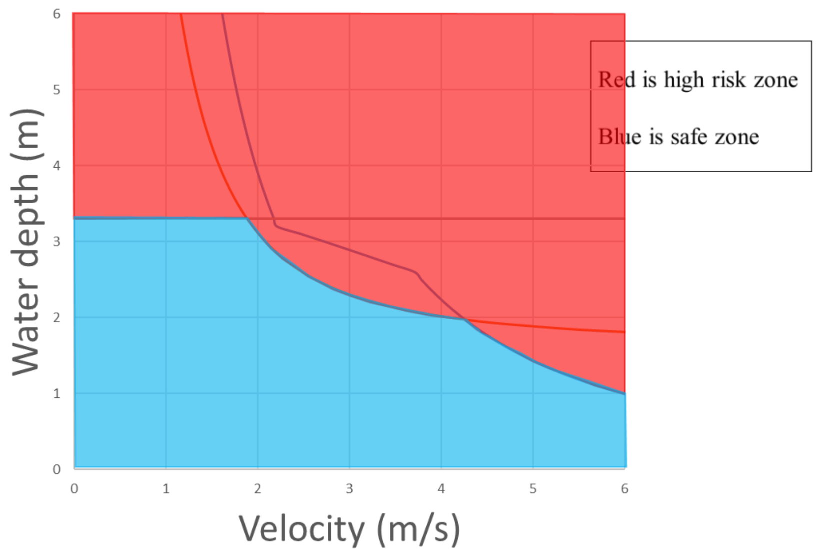

Figure 5. Two-stage flood risk identification. Red, high-risk zone; blue, safe zone.

CONCLUSION

In this study, we applied a flood inundation model to the Jinzu and Jouganji Rivers in Toyama Prefecture, Japan. Flood inundation simulations were conducted for several scenarios. A sensitivity analysis comparing DEMs with 5- and 30-m resolution was conducted, and the 30-m DEM was selected due to its reasonable accuracy and rapid computation. We also proposed a simple risk classification system based on flood inundation depth and flow velocity data. The result is an easy to use and effective flood risk hazard zone map, designed for local people, to improve responsiveness to early evacuation warnings.

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