Development of a Real Time Flood Prediction Model for Rivers in Toyama Prefecture, Japan

Shouma Ishikawa[1]; Shuichi Kure[2]; Ryuusei Yagi[3]; and Bambang Priyambodho[4]

[1]Environmental Engineering, Graduate School of Engineering, Toyama Prefectural Univ., Imizu, Toyama, Japan
[2]Dept. of Environmental Engineering, Toyama Prefectural Univ., Imizushi, Toyama, Japan. E-mail: kure@pu-toyama.ac.jp
[3]Environmental Engineering, Graduate School of Engineering, Toyama Prefectural Univ., Imizu, Toyama, Japan
[4]Environmental Engineering, Graduate School of Engineering, Toyama Prefectural Univ., Imizu, Toyama, Japan

ABSTRACT

Severe water-related disasters occur almost every year in Japan due to typhoons and frontal rains; these events often lead to evacuation problem. Many real time flood forecasting systems are available in Japan, but are designed to cover the whole of Japan, and are not calibrated to local cities or rivers. The main purpose of this study was to develop a real time flood prediction model that is suitable for use at the local community level. In this study, a physical rainfall-runoff and flood inundation model was developed to predict flood inundation situations in Toyama, Japan. According to the results of the analysis, there were significant differences between the results of the simulations using DEM resolutions of 90 and 5 m. However, it should be noted that the flood inundation simulations based on the 5 m DEM take too long for real time flood prediction.

INTRODUCTION

Severe water-related disasters occur almost every year in Japan due to typhoons and frontal rains; these events often lead to evacuation problem. Many real time flood forecasting systems are available in Japan, but such systems are designed to cover the whole country, and are not calibrated to local cities or rivers. Researchers have developed rainfall runoff and flood inundation models, and such models have been applied to several river basins in Japan, Malaysia and Indonesia (For example, Moe et al., 2017).

The main purpose of this study was to develop a real time flood prediction model that can be applied at the local community level in Toyama Prefecture, Japan. The developed model will be used to encourage local people into early evacuation, so the model needs to be accurate and the results should be fast to compute.

STUDY AREA

Toyama Prefecture is located in the central part of Honshu Island, Japan, as shown in **Figure 1**. There are five main rivers flowing into Toyama, called the Jinzu, Jouganji, Kurobe, Shou and Oyabe Rivers. These are managed by the Japanese government as class A rivers. Other small rivers managed by the Toyama Prefecture as class B rivers are also considered in this study, as shown in **Figure 1**. The largest river, the Jinzu, has a catchment area of 2,720 km^2 and length of 120 km.

It should be noted that the rivers in Toyama have very steep channels. For example, the average river bed gradient in Jouganji River is approximately 1/50. Due to these steep river segments, flooding due to river bank scouring and erosion is considered one of the biggest flood risks in Toyama.

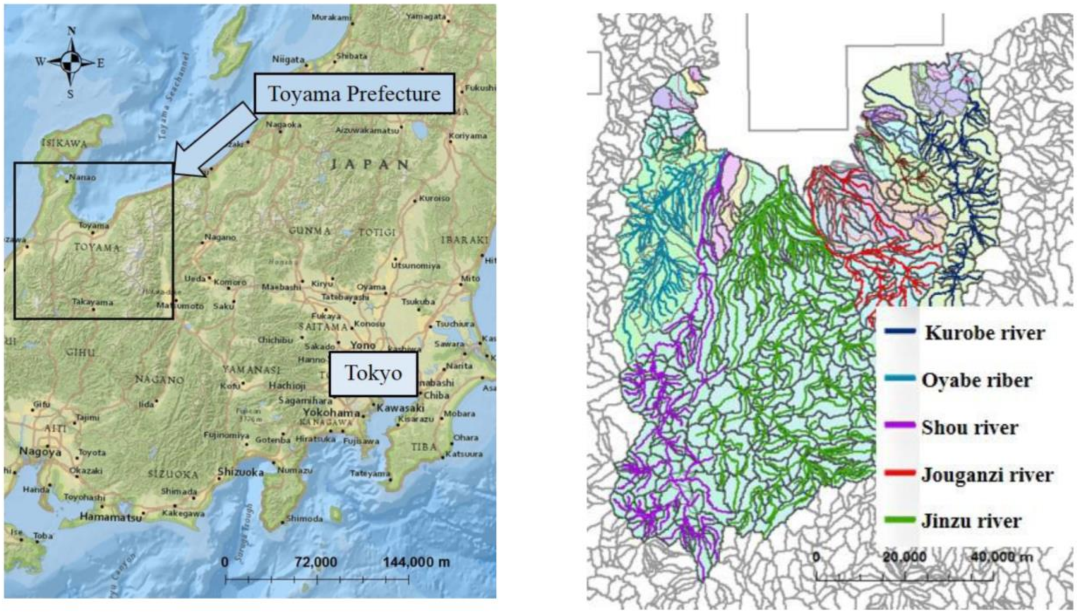

Figure 1. Location of Toyama Prefecture (left), the study area and target rivers (right)

METHODOLOGY

Flood Inundation Model

The flood inundation model consists of a rainfall-runoff module for each sub-basin, a hydrodynamic module in the rivers and canal networks, and a flood inundation module on the floodplain.

For the rainfall runoff simulation, a physical rainfall-runoff model (Kure et al., 2008, Moe et al., 2017, Priyambodoho et al., 2018) was employed because this model can simulate Hortonian overland flow in urban areas and subsurface and saturation overland flows in mountainous areas, depending on the relationship between the soil and geological characteristics and the rainfall intensity on a hillslope.

Reanalysis rainfall data based on radar and ground observation data provided by the Japan Meteorological Agency (JMA) were used as input data for the simulation. The soil parameters used in the simulation were calibrated based on five land cover classes: forest, cropland, paddy field, urban area, and water body in the target area. The calibrated parameters are shown in **Table 1**.

The Saint-Venant equations for the conservation of continuity and momentum were used to model flood routing in rivers and drainage. The unsteady two-dimensional flow equations, consisting of the continuity and momentum equations, are solved numerically for the flood inundation simulation of the flood plain. The Manning's roughness coefficients of the river beds were set from 0.03 to 0.06 for river sections, and the coefficient of the land surface was set to 0.06 for all of the floodplains, based on the results of our calibration.

Table 1. Model parameters and calibrated values

	Urban area	Paddy field	Water body	Forest	cropland
Soil depth [mm]	5	100	50	200	5
effective porosity	0.10	0.30	0.20	0.40	0.10
Saturated hydraulic conductivity[mm/h]	5	170	130	270	5
Surface roughness	0.10	0.30	0.20	0.40	0.10
Runoff coefficient	0.80	0.50	1.00	0.50	0.50

Dataset

A DEM is a raster dataset containing information about the topography of a region, and the J-FlowDir dataset (Yamazaki et al., 2018) was used in this study. Its spatial resolution is about 30 m, as shown in **Figure 2**.

The cross-section data for the rivers and drainage system in the target area were provided by the Toyama Office of River and National Highway, Ministry of Land, Infrastructure, Transport and Tourism (MLIT). River networks, sub-basin and land use/cover information were downloaded in GIS formats from the Geospatial Information Authority of Japan, MLIT. The land use/cover information is based on 12 land classifications, but the authors re-classified the land use into five classes for ease of model calibration, as shown in **Figure 3**.

Water levels and data concerning discharge into rivers were collected from the Water Information System, MLIT, and Toyama Prefecture.

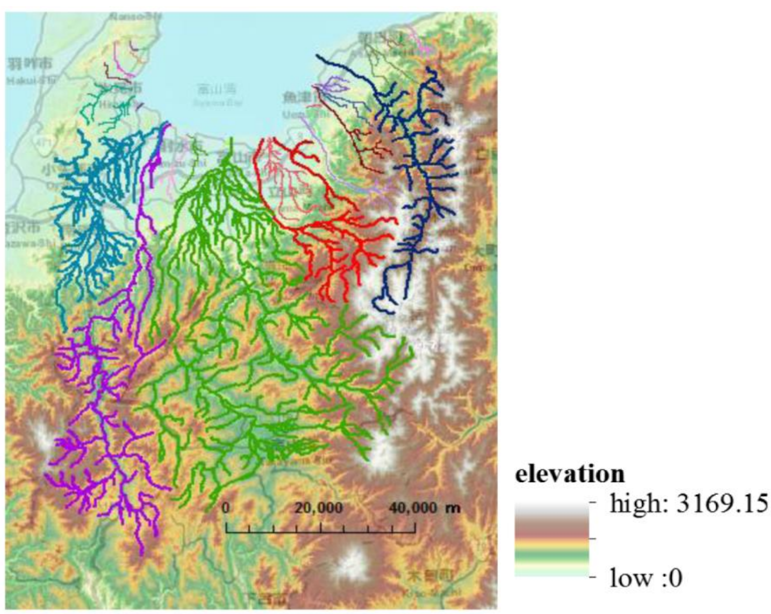

Figure 2. DEM (J-FlowDir) around study area

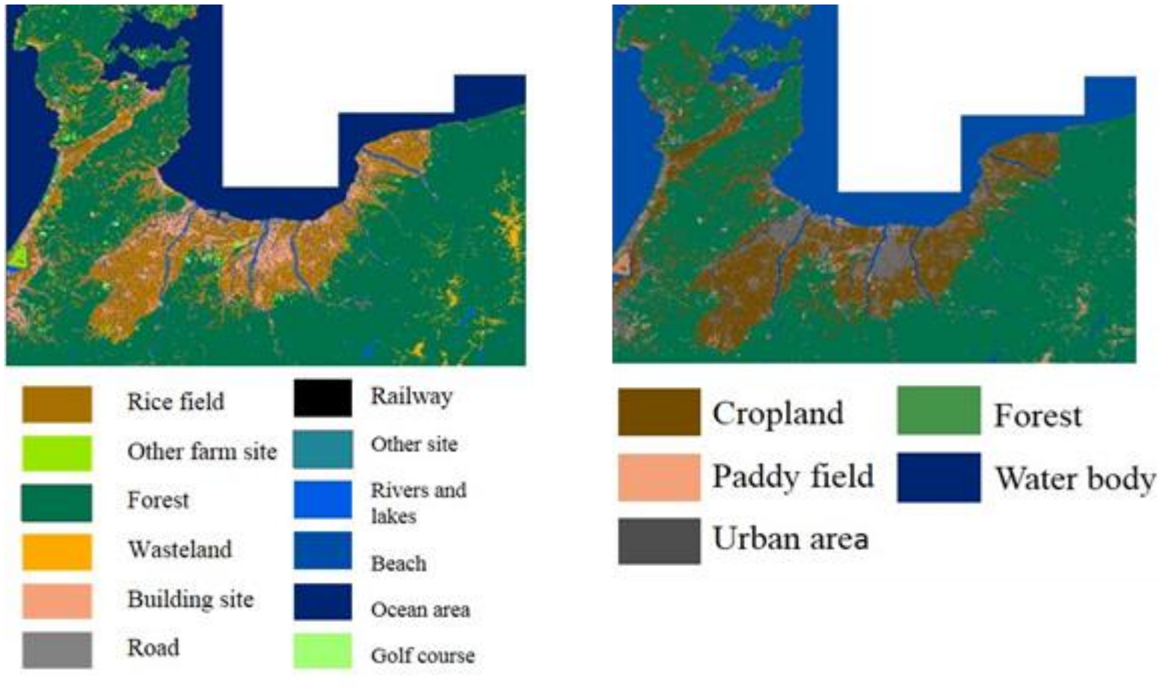

Figure 3. Land use/cover map around the study area (left:12 class, right:5 class)

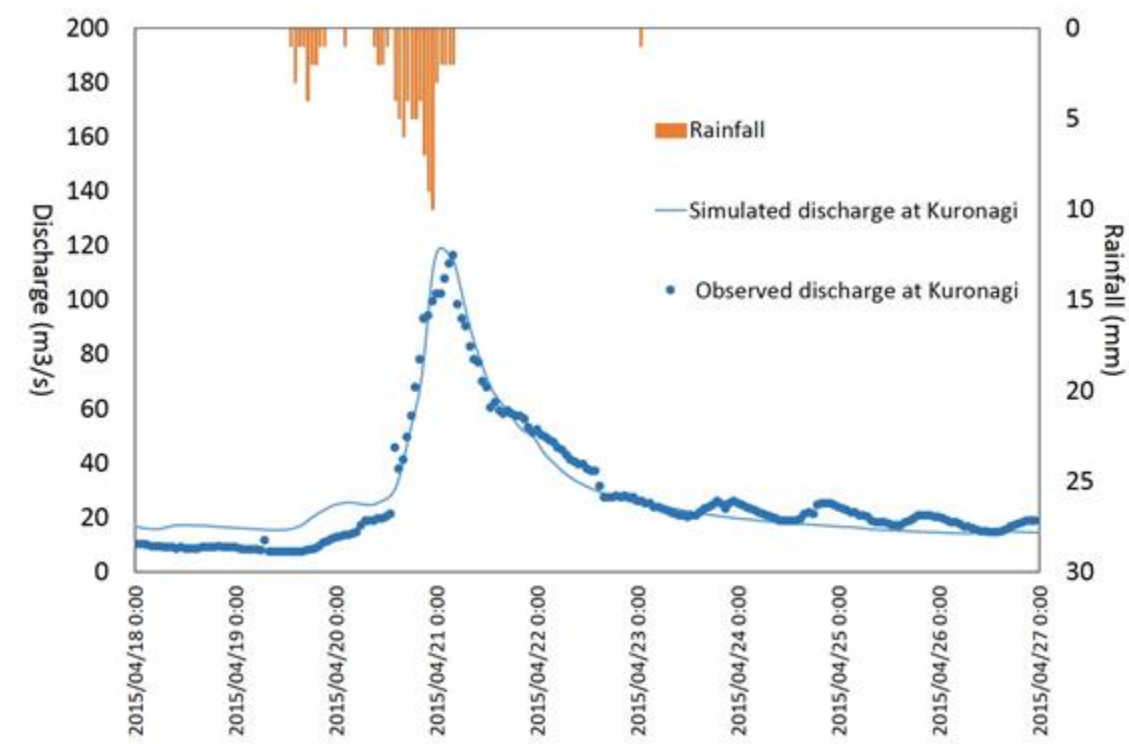

Figure 4. Comparisons between simulated and observed river discharge of the Kurobe river

RESULTS

The model was applied to the study area for the flood event of 2015. This flood event was selected as the target, because observed river discharge data are available. **Figures 4** and **5** show a comparison between the simulated and observed discharge hydrographs of the Kurobe and Shou rivers. The simulated discharge was calculated using reanalysis data based on radar and ground rainfall. The simulation results matched the observed discharge reasonably well.

In this study, we analyzed the sensitivity of DEMs with resolutions of 90, 30, and 5 m. It should be noted that the flood inundation simulation needs more time to run when a DEM with a resolution of 5 m is used rather than resolutions of 30 and 90 m. There were significant differences between the results obtained from simulations using resolutions of 90 and 5 m for evaluations at the local community level. However, it should be noted that the flood inundation simulations based on the 5 m DEM take too long to run to be used for real time flood prediction. Thus, we selected a 30 m DEM for flood inundation modelling, as a compromise between accuracy and speed.

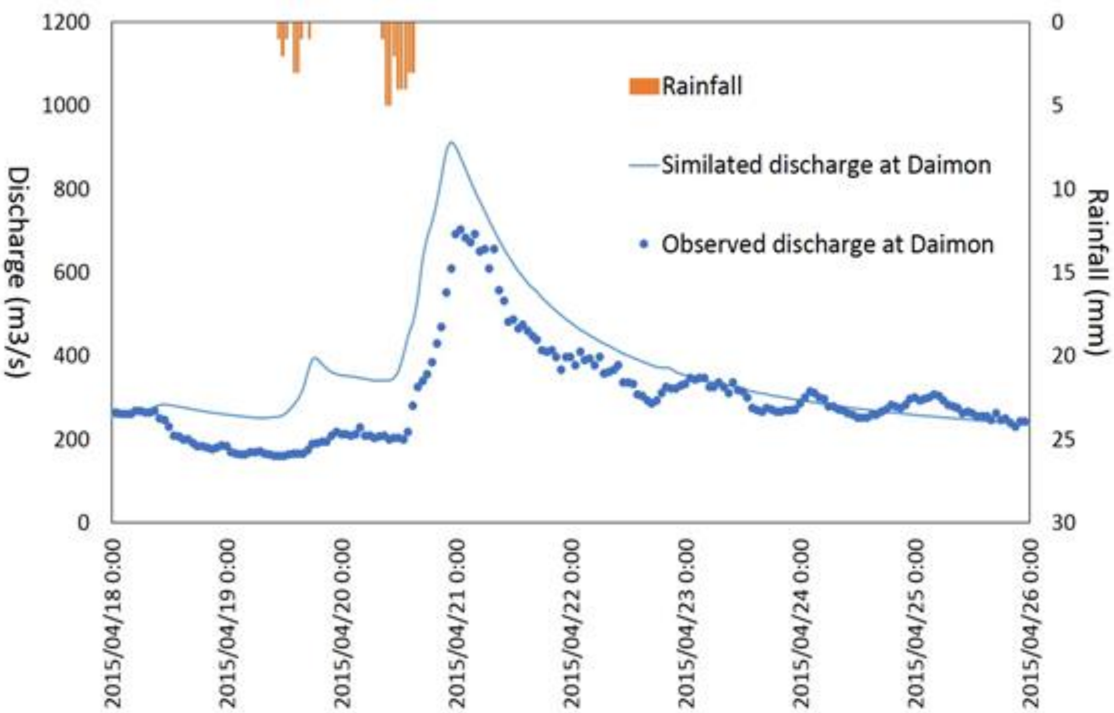

Figure 5. Comparisons between simulated and observed river discharge of the Shou river

CONCLUSIONS

In this study, a physical rainfall-runoff and flood inundation model was applied to rivers in Toyama Prefecture to develop a real time flood forecasting system and provide early warning so that local people can evacuate.

The information and datasets necessary for the simulations were collected and integrated into the model. Our validation results, based on a comparison between the observed and simulated river flow discharge at several stations, confirm that the applied model works well.

A sensitivity analysis of the model dataset was carried using different model datasets. We compared digital elevation models with resolutions of 5, 30, and 90 m and found significant differences between simulation results obtained using DEM resolutions of 90 and 5 m for assessment of local flood inundation. However, the computation with a resolution of 5 m takes too long, so we decided to use a resolution of 30 m for the real time flood forecasting system for Toyama Prefecture.

ACKNOWLEDGEMENTS

This work was supported by JSPS KAKENHI Grant Number JP18K04372 and the Environment Research and Technology Development Fund (S-14) of the Ministry of the Environment, Japan. We would like to thank the Toyama Office of River and National Highway, MLIT, for the river cross-section dataset.

REFFERENCES

Kure, S., Watanabe, A., Akabane, Y., Yamada, T. (2008). “Field observations of discharge and runoff characteristics in urban Catchments area.” Proceedings of the 11th International Conference on Urban Drainage, September 1-5, 2008 Edinburgh, Scotland; 1-10.

Moe, I.R., Kure, S., Januriyadi, N.F,. Farid, M., Udo, K., Kazama, S., and Koshimura, S. (2017). Future Projection of Flood Inundation Considering Land Use Change And Land Subsidence in Jakarta, Indonesia, Hydrological Research Letters, Vol.11, No.2, pp.99-105.

Priyambodoho B., S. Kure, I.R. Moe, and S. Kazama (2018) “Numerical Experiments of Future Land Use Change for Flood Inundation in Jakarta, Indonesia” Journal of Japan Society of Civil Engineers, Ser. G (Environment), Vol.74, No.5, I_265-I_271.

Yamazaki D., S. Togashi, A. Takeshima, T. Sayama (2018) “HIGH-RESOLUTION FLOW DIRECTION MAP OF JAPAN" Journal of Japan Society of Civil Engineers (B1), Vol.74(5), pp.I_163-I_168 (In Japanese with English abstract).