Evaluating the Impact of Rainfall Control on Flood Inundation and Economic Losses in the Kurokawa River Basin

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Introduction

Short-term extreme rainfall produced by linear rainbands poses significant hydrometeorological risks in Japan. To explore potential mitigation via weather modification—such as cloud seeding and wind-induced cloud formation—this study employs a suite of rainfall–runoff, inundation, and socio-economic models. By simulating various rainfall-control scenarios, we evaluate the effectiveness of these strategies in reducing flood impacts. Specifically, we apply these controls to a representative historical event within the target catchment to quantify potential societal and economic benefits. The results provide a comprehensive overview of rainfall control as a tool for flood mitigation and its capacity to reduce economic damage for local residents.

Methodology

In this study, we selected the Kurokawa River basin as the target area (**Fig. 1**) due to its significant exposure to linear-shaped heavy rainfall events. Two rainfall datasets were used: simulated rainfall from the Weather Research and Forecasting (WRF) model and historical Radar–AMeDAS precipitation data.

Using the WRF simulations, rainfall-control scenarios based on the seeding-core method were applied to evaluate the effectiveness of rainfall modification. To address the limited number of case studies, we employed a counterfactual approach to generate an ensemble of scenarios by slightly shifting the rainfall-band mesh northward (N) and eastward (E) over the catchment. The displacement distances for each mesh shift were 0.031° north and 0.0266° east.

Applying these reduction ratios to the historical July 2012 heavy rainfall event allowed us to evaluate whether similar control effects could mitigate flooding under comparable conditions. Inundation was simulated using the Integrated Model for Channel and Floodplain Flow with Inertial Terms (IMCR), which incorporates local inertial equations for one-dimensional (1-D) river flow and two-dimensional (2-D) overflow processes. River discharge inputs were generated using the 1-D kinematic wave model, 1K-DHM. Finally, the resulting inundation maps were used to estimate economic damage by integrating exposure data provided by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

Results and Discussions

As shown in **Figs. 2** and **3**, a 10% decrease in 24-hour basin-averaged rainfall results in a 14.63–23.98% reduction in peak discharge (excluding overflow) and a 15.89–29.42% decrease in inundation extent. The most significant improvements were observed in deeper-water areas (water depth > 1 m). However, the efficacy of rainfall control in mitigating flood inundation is highly sensitive to the spatial and temporal characteristics of the precipitation. Variations in rainband location and the positioning of high-intensity cells significantly influence peak-discharge reduction. Even with consistent reductions in total rainfall, runoff responses varied across scenarios, suggesting that more aggressive suppression is necessary for higher-intensity rainfall events, particularly when high-intensity area coverage exists in downstream regions, to achieve substantial flood mitigation.

Regarding socio-economic impacts, total damage decreases by approximately 1 billion yen under rainfall control, mainly due to reduced losses to household assets and property, while agricultural damage to rice and field crops shows limited reduction. This contrast reflects the modest decrease in inundation extent in agricultural areas compared with the pronounced water-level reductions in densely populated urban zones.

Analysis of human damage by age and housing type indicates that inundation risk disproportionately affects elderly residents in single-story houses, underscoring the importance of mitigation measures for this vulnerable group.

Conclusion

This study demonstrates that rainfall-control strategies can meaningfully reduce flood risks in the Kurokawa River basin. A 10% decrease in rainfall yields notable reductions in peak discharge, inundation extent, and associated economic losses. Effectiveness depends strongly on rainband position and rainfall intensity, indicating targeted suppression during high-impact periods is essential. While household and property damages decline significantly, agricultural benefits remain limited. Overall, rainfall modification shows potential as a supplementary flood-mitigation measure with measurable socio-economic gains.

Acknowledgment

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References

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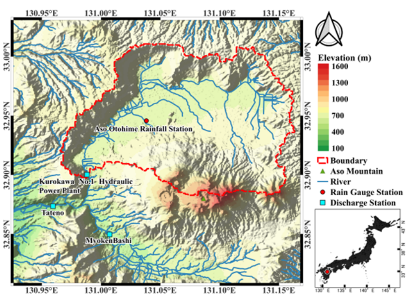

Fig. 1 Study area.

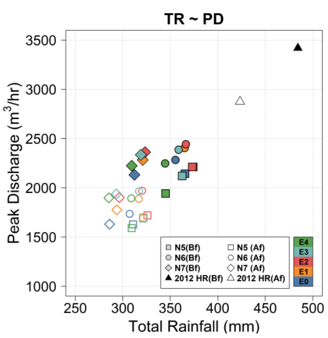

Fig. 2 River discharge changing.

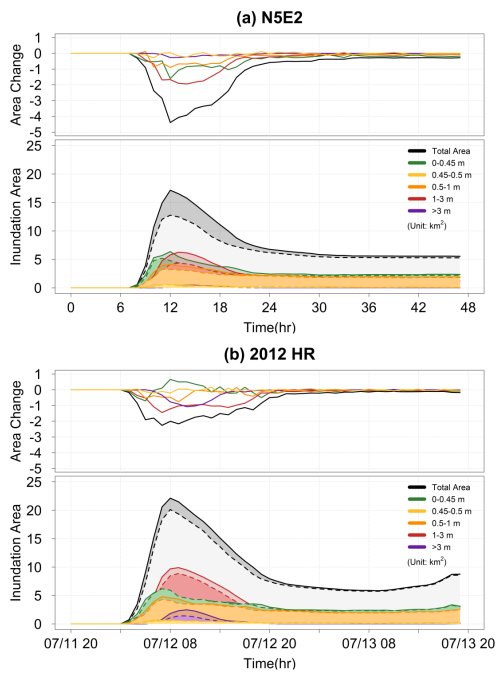

Fig. 3 Inundation change of different water depth.