Long-term changes in the spatial distribution of economic activity due to increased flood risk

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1. Introduction

Background：

- In recent years, the flood risk has increased as a result of climate change.
- This increased flood risk can cause significant damage to economic activity.
- To mitigate this damage, it is important to assess mitigation policies in advance.
  - As shown in the figure2, it is necessary to capture the spatial distribution of both flood risk and economic activity.
  - Findings from empirical analyses in the field of spatial economics show that it is important to consider agglomeration economies in order to capture long-term changes in the spatial distribution of economic activity.

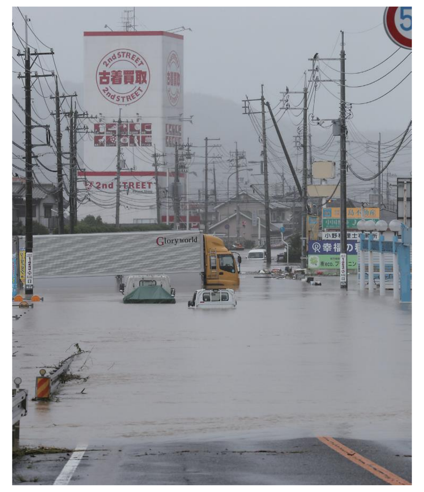


Fig. 1. Damage to Economic Activity Associated with Climate Change: 2018 Heavy Rainfall in Japan

Problems with Previous Studies：

A) Models that take into account both agglomeration economies and flood risk are not in place.

B) Models that consider agglomeration economies are difficult to analyze numerically on a large scale.
For this reason, applied analysis using such models for real areas has not progressed.

C) Parameter setting methods are not yet in place.

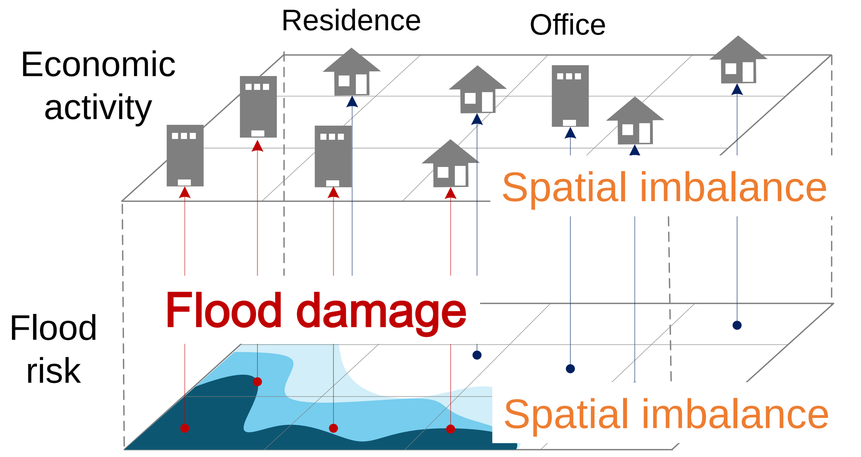


Fig. 2. Spatial distribution of flooding risk and economic activity

Objective：

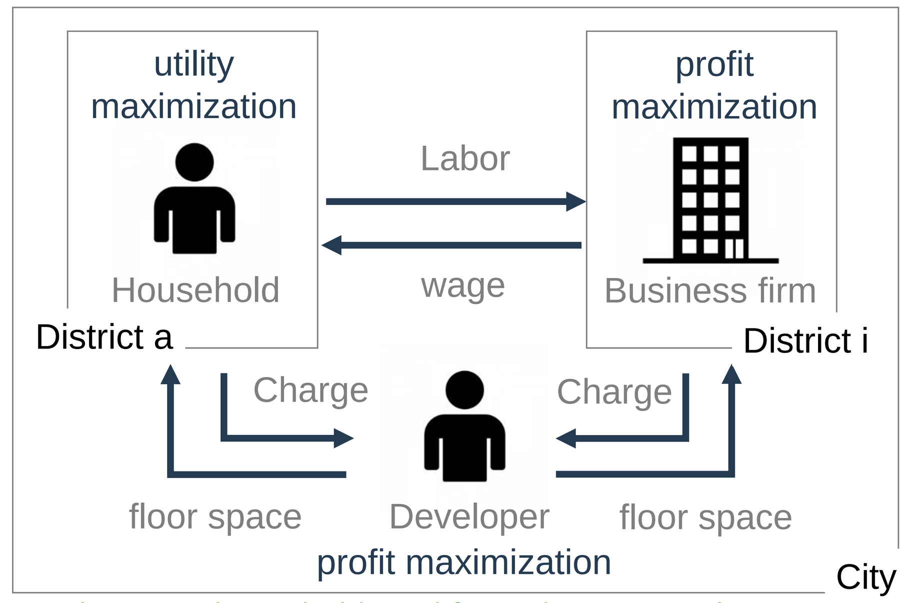
this study addresses these problems

- This study aims to develop an urban economic analysis method that can measure the long-term impact of flood risk changes on the spatial distribution of economic activity.

2. Model

Addressing Problem A

- We built a model to address Problem A. Specifically, based on Fujita and Ogawa(1982), we constructed a model that takes into account flood risk and agglomeration economies.
  - In the equation shown below, agglomeration economies are taken into account in the orange part of the model. The red part of the model is a framework in which flood risk can be taken into account.



Interaction between households and firms determines their respective locations.

Fig. 3. Structure of the model

Household behavior

Amenity level

$$\max u_{ai} = z_{ai} + \boldsymbol{A_a}$$

Flooding risk can be taken into account.

wage, composite commodity, Land rent, Commuting cost

$$\text{s.t. } w_i = z_{ai} + r_a s^H + t\tau_{ai}$$

The closer to the business firm, the lower the cost

Business firm behavior

Profit, Production, Land rent, wage

$$\max \pi_i = P_i(\boldsymbol{m}) - r_i s^F - w_i$$

Location-specific effects

$$P_i(\boldsymbol{m}) = \alpha \textstyle\sum_{j\in\mathcal{L}} \exp[-\rho\tau_{ij}] m_j + \boldsymbol{B_i}$$

Flooding risk can be taken into account.

Term representing agglomeration economies
⇒The closer/more companies are to each other, the more productive they are.

Developer behavior

Profit, Capital, Land rent paid to landowner, Land area, opportunity cost, Floor space supply

$$\max \Pi_a = r_a S_a - PM_a - (R_a + C)K_a \quad \text{s.t.} \quad S_a = M_a^{\mu} K_a^{1-\mu}$$

3. Location equilibrium conditions and Stability analysis

Addressing Problem B

- As addressing Problem B, we have shown that a potential function exists in the constructed model.
- This allows the model to be analyzed numerically on a large scale.

Measurement by the model requires a stability analysis with location equilibrium conditions.

Location equilibrium conditions

$$h_{ai} = \frac{\exp[\theta u_{ai}(\boldsymbol{h})]}{\sum_{b\in\mathcal{L}}\sum_{j\in\mathcal{L}} \exp[\theta u_{bj}(\boldsymbol{h})]} N$$

Total population (N)

Conditions for existence of potential functions

$$\frac{\partial f(\boldsymbol{h})}{\partial h_{ai}} = u_{ai}(\boldsymbol{h}) - \frac{1}{\theta}\ln h_{ai} + \zeta \quad \forall a, i \in \mathcal{L}$$

Scale parameters (θ), constant (ζ)

Potential function

$$f(\boldsymbol{h}) = \sum_{i\in\mathcal{L}} \left\{\frac{\alpha}{2} F_i(\boldsymbol{m}) + B_i\right\} m_i - \sum_{a\in\mathcal{L}} (s^H n_a + s^F m_a)^{\frac{1}{\mu}} K_a^{-\frac{1-\mu}{\mu}} - t\sum_{a\in\mathcal{L}}\sum_{i\in\mathcal{L}} \tau_{ai} h_{ai} + \sum_{a\in\mathcal{L}} A_a n_a - \frac{1}{\theta}\sum_{a\in\mathcal{L}}\sum_{i\in\mathcal{L}} h_{ai}\ln h_{ai}$$

Land area (K_a)

Stability analysis is easy due to the existence of potential functions（Sandholm, 2001）

4. Parameter set method

Addressing Problem C

- As addressing Problem C, we presented a systematic way to set the parameters. The parameters were set in a stepwise manner.

$$\mu \longrightarrow s^H, s^F \longrightarrow \theta \longrightarrow \alpha,\ \boldsymbol{\kappa}^{\mathrm{AME}},\ \boldsymbol{\kappa}^{\mathrm{UNI}},\ \boldsymbol{\nu}^{\mathrm{AME}},\ \boldsymbol{\nu}^{\mathrm{UNI}}$$

The least-squares method, location equilibrium conditions, etc.

- α , $\boldsymbol{\kappa}^{\mathrm{AME}}$, $\boldsymbol{\kappa}^{\mathrm{UNI}}$, , $\boldsymbol{\nu}^{\mathrm{AME}}$, $\boldsymbol{\nu}^{\mathrm{UNI}}$ are estimated by stepwise method for variable selection and parameter estimation.

Candidate variable

- Road density
- Distance to the nearest station
- Distance to nearest IC
- Zoning Area :Residential / Commercial / Industrial
- Percentage of zoning area to land area :：Residential / Commercial / Industrial
- Water supply area dummy
- Assumed flooding depth of the planned scale
- Square of the assumed flood depth of the planned scale

Amenity level

$$A_a = \boldsymbol{\kappa}^{\mathrm{AME}} \boldsymbol{X}_a^{\mathrm{AME}} + \boldsymbol{\nu}^{\mathrm{AME}} \boldsymbol{Z}_a + \mathrm{const}_{\mathrm{A}}$$

Production

$$\mathrm{Prod}_i = \alpha \textstyle\sum_{j\in\mathcal{L}} \exp[-\rho\tau_{ij}] m_j + \boldsymbol{\kappa}^{\mathrm{UNI}} \boldsymbol{X}_i^{\mathrm{UNI}} + \boldsymbol{\nu}^{\mathrm{UNI}} \boldsymbol{Z}_i + \mathrm{const}_{\mathrm{P}}$$

Term representing agglomeration economies | Measure Variable Term | Term on variables of spatial correlation | constant term

5. Impact of increased flood risk

- Using the development methodology, we studied the impact of increased flood risk.

Target area：

Kanazawa Urban Employment Area, 1656 districts

Analytical conditions：

- This analysis studied the case where the flood risk is increased from the planned scale of flood depth to the assumed maximum scale of flood depth.

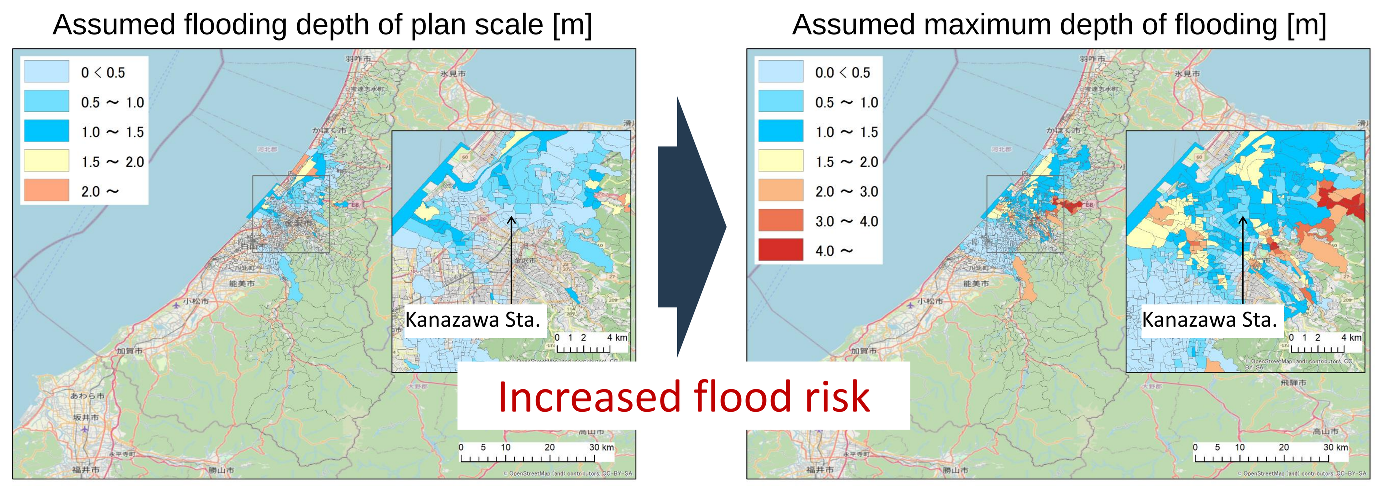


Fig. 4. Change in flood depth

Key parameter settings：

- For households, the flood risk variable is selected.

Table 1. Variables and estimates for amenity levels (household)

Item (κ^{AME})	value	t-value
Road Density	1.472.E+07	5.33
Residential area	4.417.E-04	3.07
Commercial area	3.945.E-03	4.79
Percentage of commercial area	-3.794.E+02	-4.65
Percentage of industrial area	-2.836.E+02	-5.89
Water supply area dummy	7.753.E+02	14.81
Square of the assumed flood depth	-6.257.E+01	-2.19

Table 2. Variables and estimates for production (business firm)

Item($\alpha, \kappa^{\mathrm{UNI}}$)	value	t-value
α	1.449.E-02	5.08
Road Density	7.326.E+06	5.61
Residential area	6.853.E-04	10.98
Commercial area	1.572.E-03	5.30
Industrial area	7.199.E-04	11.13
Percentage of residential area	-1.129.E+02	-6.53
Water supply area dummy	2.635.E+02	12.07

Result：

- Results are shown in Figures 5 and 6. We could see a decrease in the central city location.
- As shown in Table 3, we could see differences in the flooded area population compared to the case where the method was not used.
- This indicates that this method can measure long-term changes in economic activity due to increased flood risk.

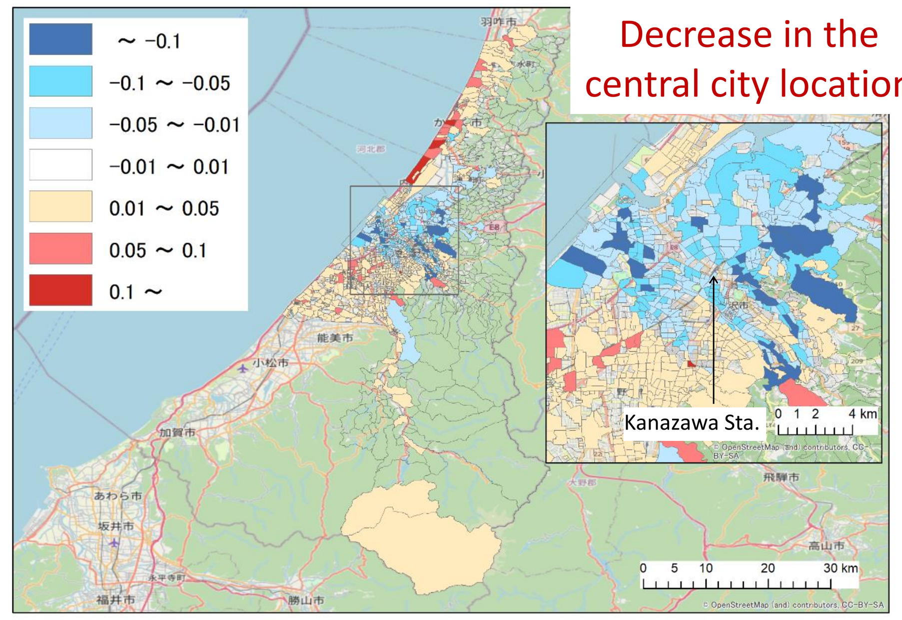


Fig. 5. Share change in household location

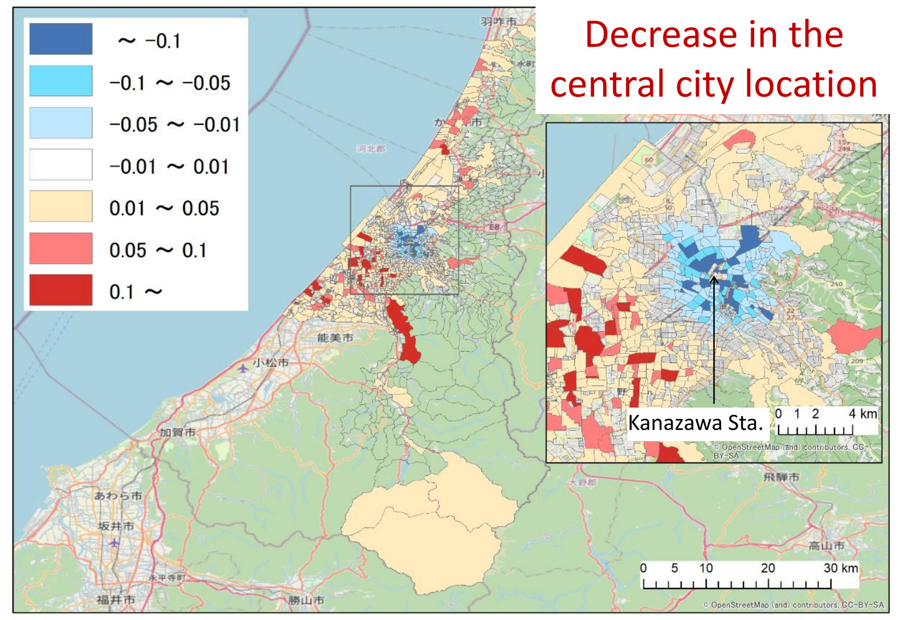


Fig. 6. Share change in business firm location

Table 3. Population of flooded area under each condition　Differences learned by this method

	Item		[Reference case]	[1]	[2]
Conditions	Flood scale	Planed scale	○		
		Assumed maximum		○	○
	Location Distribution	Before change (present)	○	○	
		After change			○
Result	Population of flooded area	Entire area	126,432	**275,755**	**250,619**
		Areas with flood depth of 0.5 meters or greater(Avg.)	40,985	172,575	120,830
		Areas with flood depth of 3.0 meters or greater(Max)	21,028	91,958	56,270