Long-Term Effect of Perceiving Flood Risk with Fuzzy Location Equilibrium Model

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***Abstract* – In the present study, the location equilibrium model was built which has three advantageous good points. They are 1) appreciation of fuzzy reasoning for describing ambiguity and complexity in the location choice behavior, 2) using the GIS data for performing the detailed spatial analysis in urban area and 3) make use of the rules of fuzzy reasoning for analyzing the change of urban population structure according to generation. This model evaluated the long-term effect on the change of location distribution caused by the flood risk perception of citizens. As a result of that, the significance of implementing the promotion measure of flood risk perception was shown.**

***Keywords* – Fuzzy Reasoning, Risk Perception, Location Choice Behavior, GIS, Flood Control**

I. INTRODUCTION

Many flood control measures have been performed in Japan. In consequence, the prevention level against flood disaster improved. Flood control measures make the generating frequency of flood disaster small. However, the housing and building land development progresses in many hazardous areas, in order that residents are optimistic about a flood risk. Therefore, the damage is serious on the contrary, if a catastrophic flood disaster occurs (Burton et al. [1993]). Although the catastrophic flood risk subsists in the present-day city, the flood risk is hard to be perceived owing to its scarcity. In addition, irrational pattern of land use is formed. From the above, it can be said that not only hard measures such as flood control works and flood control facilities construction etc. are necessary, but also soft measures are necessary. For example, leading the rational land use to balance with flood disaster risks.

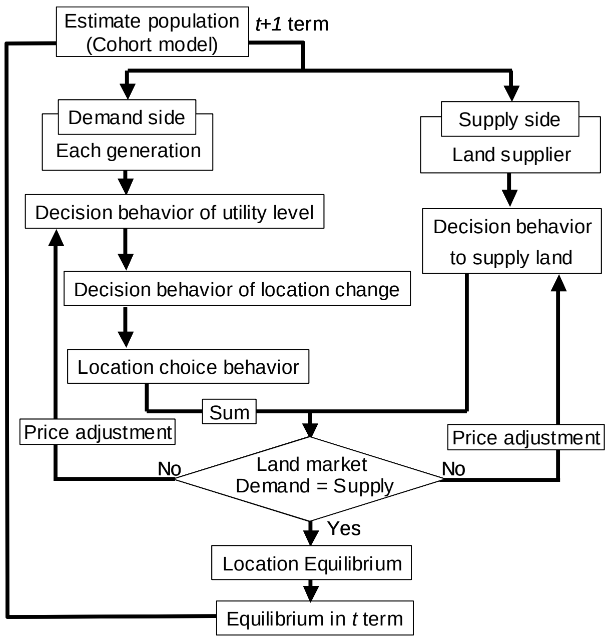

Figure 1. *Outline of fuzzy location equilibrium model*

Flood disaster risk information through flood hazard map is popular now-a-days. The first purpose of such measures is to mitigate the human damage by inducing a prompt evacuation behavior at the time of flood disaster generating. Furthermore, such measures lead the desirable land use form on flood disaster risk management by attracting removal of citizens. (Tatano [2005]).

In this paper, the perception structure for flood risk and the others in the decision making of location choice is described by using the fuzzy reasoning. Furthermore, the effect caused by the promotion measure for the flood risk perception is analyzed focusing on land use change.

Table 1. *The fuzzy reasoning rules applied to the decision behavior model of utility level for location choice*

Rule		Input				Output	0-19	20-34	35-49	50-64	65+
[I]	1	Land price	VERY LARGE			SMALL				*	
	2	Land price	LARGE			MEDIUM				*	
	3	Land price	LARGE			SMALL	*	*	*		*
	4	Land price	MEDIUM			MEDIUM	*	*	*		*
	5	Land price	MEDIUM			VERY SMALL				*	
	6	Health care service	VERY LARGE			VERY LARGE	*	*	*		
	7	Health care service	LARGE			LARGE	*	*	*	*	*
	8	Health care service	MEDIUM			MEDIUM	*	*	*	*	
	9	Health care service	SMALL			VERY SMALL	*	*	*	*	*
	10	Health care service	VERY LARGE	Convenience of public transport	VERY LARGE	VERY LARGE				*	*
	11	Health care service	MEDIUM	Convenience of public transport	LARGE	MEDIUM					*
	12	Shopping	VERY LARGE			VERY LARGE	*	*	*	*	
	13	Shopping	VERY LARGE			LARGE					*
	14	Shopping	LARGE			LARGE	*	*	*	*	*
	15	Shopping	MEDIUM			MEDIUM	*	*	*	*	
	16	Shopping	MEDIUM	Convenience of public transport	LARGE	LARGE					*
	17	Shopping	SMALL	Convenience of public transport	LARGE	MEDIUM	*	*	*	*	*
[II]	1	Distance to city center	VERY LARGE			VERY SMALL					*
	2	Distance to city center	LARGE			SMALL	*	*	*	*	*
	3	Distance to city center	MEDIUM	Convenience of public transport	LARGE	MEDIUM	*	*	*	*	*
	4	Distance to city center	SMALL			VERY LARGE	*	*	*		*
	5	Distance to city center	SMALL			LARGE				*	
	6	Convenience for public transport	LARGE			LARGE				*	*
	7	Convenience for public transport	MEDIUM			MEDIUM				*	*
	8	Natural environments	VERY LARGE			SMALL	*	*	*	*	*
	9	Natural environments	LARGE			LARGE	*	*	*		
	10	Natural environments	SMALL			SMALL	*	*	*	*	*
	11	Natural environments	LARGE	Aging community	LARGE	SMALL				*	*
[III]	1	Risk of flood disaster	VERY LARGE			SMALL	*	*	*	*	*
	2	Degree of mixture house and factor	VERY LARGE			SMALL	*	*	*	*	*
[IV]	1	Aging community	SMALL			SMALL				*	*
	2	Aging community	LARGE	Rate of living together	LARGE	LARGE				*	*
	3	Neighborhood acquaintance	VERY LARGE	Rate of living together	SMALL	SMALL					*
	4	Neighborhood acquaintance	LARGE	Rate of living together	SMALL	SMALL				*	
	5	Neighborhood acquaintance	LARGE			LARGE		*	*	*	
	6	Neighborhood acquaintance	SMALL			VERY SMALL				*	*
	7	Attachment to domicile	SMALL	Aging community	LARGE	MEDIUM				*	

I: Life service, II: Convenience and amenity, III: Relief and safety, and IV: Community and living environment.

*: the rule applied to the decision behavior model of utility level for location choice.

II. FUZZY LOCATION EQUILIBRIUM MODEL

A. *Outline of fuzzy location equilibrium model*

Outline of fuzzy location equilibrium model is shown in Figure 1. The society has only two subjects those are the land supplier and the individual who demands the land and choose the location. Since the location choices and decision behaviors of each generation are different, the model is classified into five generations of 0 to 19 years old, 20 to 34 years old, 35 to 49 years old, 50 to 64 years old, and 65 or more years old. First, The appeal degree of land is estimated by the decision behavior model of utility level that is described by using fuzzy reasoning. Next, the decision behavior model of location change that is described by Binary Logit model determines whether the individual changes location. Thirdly, the location choice behavior model that is described by Multinominal Logit model determines which location zone the individual who decided to change location chooses. On the other hand, the behavior of land supplier who determines how many land area develop and supply to the individual who changes a location is also described by using fuzzy reasoning. The amount of land demand and supply determined by the above processes is balanced by the price adjustment mechanism in the land market in each zone. Therefore, the amount of location change from a certain term to the next term is estimated in each zone, and finally, the amount of location in the next term is estimated in each zone. Furthermore, the location changes are estimated at many terms by repeating this process.

B. *Decision behavior of utility level*

Utility level u_j is estimated by the fuzzy reasoning rules and the membership functions according to the environmental factors those affect the behavior of location choice. The fuzzy reasoning rules are determined by which environmental factor has how many influences on the appeal of land as shown in the equation (1).

$$
\begin{aligned}
&\text{Rule 1: } IF\ \ x\ is\ a_1\ \ and\ \ y\ is\ b_1\ \cdots,\ Then\ \ u_1\ is\ c_1\\
&\text{Rule 2: } IF\ \ x\ is\ a_2\ \ and\ \ y\ is\ b_2\ \cdots,\ Then\ \ u_2\ is\ c_2\\
&\quad\vdots\\
&\text{Rule n: } IF\ \ x\ is\ a_n\ \ and\ \ y\ is\ b_n\ \cdots,\ Then\ \ u_n\ is\ c_n
\end{aligned}
\qquad (1)
$$

where x, y: environmental condition, u_j: utility level, a_j, b_j, c_j: linguistic variables.

The form of membership function is represented to the triangle fuzzy number using the linguistic variable as small, medium, large, and very large. Table 1 shows the fuzzy reasoning rules those applied to each generation. The rules are categorized into "I: Life service", "II:

Convenience and amenity", "III: Relief and safety", and "IV: Community and living environment" according to the environmental factors those constitute the land appeal.

C. Decision behavior of location change

The probability of location change P_i^* at each zone is estimated by substituting the utility level u_i at each zone and the average utility level $\bar{u}_i$ in the whole area for the Binary Logit model shown as the equation (2). An average utility level $\bar{u}_i$ is estimated by the equation (3). Therefore, the number of location change $N_i^*(t)$ at each zone is determined by multiplying the probability of location change P_i^* by the generation population $N_i(t)$ as shown in the equation (4).

$$P_i^* = \frac{\exp(\bar{u}_i)}{\exp(u_i) + \exp(\bar{u}_i)} \quad (2)$$

$$\bar{u}_i = \ln\left[\sum_{j=1}^{J} \exp(u_j)\right] - c_i \qquad (j \neq i) \quad (3)$$

$$N_i^*(t) = P_i^* \cdot N_i(t) \quad (4)$$

where c_i : the feeling of resistance to location change.

D. Location choice behavior

The probability of location choice P_{ij} to zone j is estimated by substituting the utility level u_i at each zone for the Multinominal Logit model shown as the equation (5). The population $N_j(t+1)$ at zone j is determined by multiplying the probability of location choice P_{ij} by the number of location change $N_i^*(t)$ at each zone as shown in the equation (6).

$$P_{ij} = \frac{\exp(u_j)}{\sum_{j=1}^{J} \exp(u_j)} \qquad (j \neq i) \quad (5)$$

$$N_j(t+1) = N_j(t) - N_j^*(t) + \sum_{i=1}^{I} P_{ij} \cdot N_i^*(t) \quad (6)$$

E. Land demand

The land demand per head q_j is estimated by defining the land demand function $q_j(\cdot)$ which describes the relation between the land price ρ_j at each zone and the land demand per head q_j as shown in the equation (7). Therefore, the amount of land demand Q_j at each zone is determined by the equation (8).

$$q_j = q_j(\rho_j) \quad (7)$$

$$Q_j = q_j \cdot \left[\sum_{i=1}^{I} P_{ij} \cdot N_i^*(t) - N_j^*(t)\right] \quad (8)$$

Table 2. *The fuzzy reasoning rules applied to the behavior model of land supplier*

Rule		Input				Output
[I]	1	Land price	LARGE			LARGE
	2	Land price	MEDIUM			MEDIUM
	3	Land price	SMALL			SMALL
	4	Health care service	LARGE			VERY LARGE
	5	Health care service	MEDIUM			MEDIUM
	6	Health care service	SMALL	Convenience of public transport	VERY LARGE	MEDIUM
	7	Shopping	LARGE			VERY LARGE
	8	Shopping	MEDIUM			MEDIUM
	9	Shopping	SMALL	Convenience of public transport	LARGE	MEDIUM
	10	Distance to city center	LARGE			SMALL
	11	Distance to city center	MEDIUM	Convenience of public transport	LARGE	MEDIUM
	12	Natural environments	MEDIUM			MEDIUM
	13	Natural environments	SMALL			SMALL
[II]	1	Risk of flood disaster	VERY LARGE	Aging community	LARGE	SMALL
	2	Degree of mixture house and factory	VERY LARGE			SMALL
	3	Aging community	VERY LARGE	Rate of living together	LARGE	SMALL
[III]	1	Urban district	LARGE			MEDIUM
	2	Urban district	SMALL			SMALL
	3	Time of land adjustment	LARGE			SMALL
	4	Time of land adjustment	MEDIUM			MEDIUM
	5	Time of land adjustment	SMALL			VERY LARGE

I: Obtainablity of profit, II: Risk subsisted in land, and III: Urban planning-factor.

F. Behavior of land supplier

The rate of development r_j is estimated by the fuzzy reasoning rules and the membership functions according to the environmental factors those affect the behavior of supplying land. The fuzzy reasoning rules are determined by which environmental factor has how many influences on development as shown in the equation (9).

$$\begin{aligned}
&\text{Rule 1}: \ IF \ \ x \ is \ A_1 \ \ and \ \ y \ is \ B_1 \ \cdots, \ Then \ \ r_1 \ is \ C_1 \\
&\text{Rule 2}: \ IF \ \ x \ is \ A_2 \ \ and \ \ y \ is \ B_2 \ \cdots, \ Then \ \ r_2 \ is \ C_2 \\
&\qquad \vdots \\
&\text{Rule n}: \ IF \ \ x \ is \ A_n \ \ and \ \ y \ is \ B_n \ \cdots, \ Then \ \ r_n \ is \ C_n
\end{aligned} \quad (9)$$

where x, y : environmental condition, r_j : development rate, A_j, B_j, C_j : language variable.

The form of membership function is represented to the triangle fuzzy number using the linguistic variable as small, medium, large, and very large. The fuzzy reasoning rules are shown in Table 2. The fuzzy reasoning rules are categorized into "I: Obtainablity of profit", "II: Risk subsisted in land", and "III: Urban planning-factor".

The amount of land supply L_j is determined by multiplying the rate of development r_j by the available area W_j at each zone as shown in the equation (10).

$$L_j = r_j \cdot W_j \quad (10)$$

G. Equilibrium between land demand and supply

The amount of location at each zone is determined by work of a market mechanism with which the amount of land demand and supply balances at each zone. The equilibrium condition of land demand Q_j and the land supply L_j is given as the following equation.

$$Q_j = L_j \tag{11}$$

III. FLOOD CONTROL WORK AND PROMOTION OF FLOOD RISK PERCEPTION

A. Outline of two kinds of measures for flood risk management

We analyze two kinds of measures those are the flood control work and the promotion of flood risk perception for flood risk mitigation. It is assumed that the flood control work decreases the flood risk equally in the whole area as shown in Figure 2. It is assumed that the promotion of flood risk perception changes the level (inundation depth) judged to be dangerous by disaster education etc. The membership function of the flood risk perception in the decision behavior model of utility level for location choice is specifically shown in Figure 3. The parameter of the level for dangerous are changed. For example, the perception that is "it is dangerous if a flood risk (inundation depth) is 7m" changes to the perception that is "4m is dangerous" as shown in Figure 4 (Left figure). It is assumed that the perception that is "it is a little dangerous if a flood risk is 3m" changes to the optimistic perception that is "6m is a little dangerous" as shown in Figure 4 (Right figure). The assumption of the measure of each case is shown in Table 3.

B. Analysis of location changes

The effects cased by the promotions of flood risk perception and the flood control works are compared focusing on the location change. Figure 5 shows the distributions of location change caused by the flood control work [CASE III] in the left figure and the promotion of flood risk perception [CASE 1] and [CASE 4] in the middle and right figure, respectively.

It is observed that the tendency for the flood control works such as [CASE III] increase the amount of location change at the meshes with a high flood risk. On the contrary, the promotion of flood risk perception such as [CASE1] causes the tendency for the amount of location change to decrease at the meshes with a high flood risk. The tendency for the amount of location change to increase at the meshes with a high flood risk is shown as the right figure, if a flood risk perception becomes optimistic such as [CASE4]. Therefore, a flood control

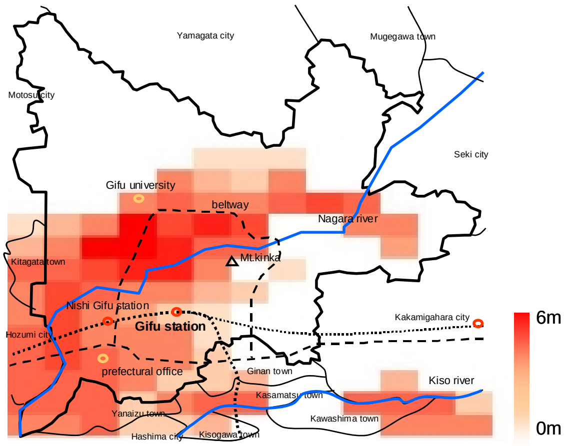

Figure 2. *Distribution of flood risk (inundation depth)*

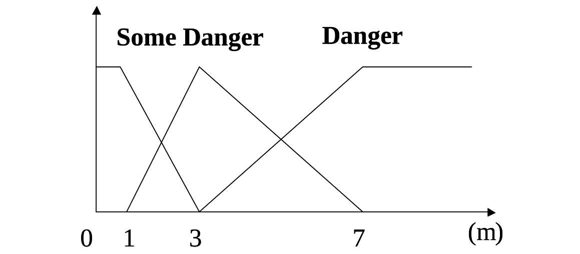

Figure 3. *Membership function of flood risk perception*

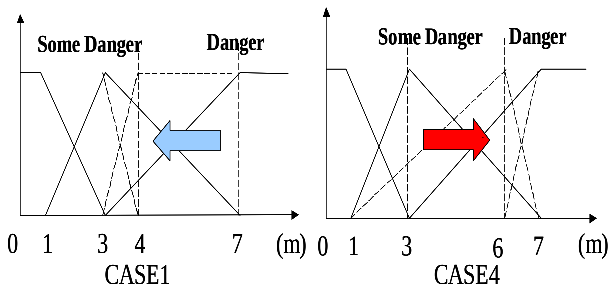

Figure 4. *How to represent the change of flood risk perception*

Table 3. *The summary of measures*

CASE	Substances of measure
CASE I	3% decrease flood risk (inundation depth)
CASE II	5% decrease flood risk (inundation depth)
CASE III	10% decrease flood risk (inundation depth)
CASE IV	15% decrease flood risk (inundation depth)
CASE 1	Membership function turns into 4m from 7m
CASE 2	Membership function turns into 5m from 7m
CASE 3	Membership function turns into 2m from 3m
CASE 4	Membership function turns into 6m from 3m (Flood risk perception becomes optimistic)

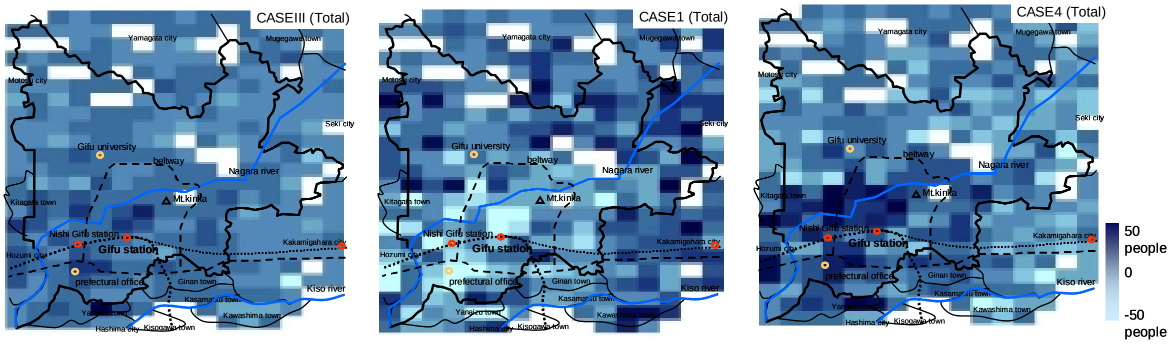

Figure 5. *Distributions of location change (CASE III, CASE 1 and CASE 4)*

work may increase the damage potential against a catastrophic flood disaster. On the other hand, if residents perceived a flood risk correctly by disaster information dissemination and disaster education, etc., the behavior of averting a flood risk is promoted, and residents may move from dangerous area to safe area.

C. Analysis of expected values of flood risk

Figure 6 shows the expected values of flood risk in the whole urban area at the time of performing each measure by setting the present condition to 1.0. It is shown in the results of [CASE I] to [IV] that the effect of flood risk reduction becomes large as the level of flood control work is raised. In the promotion of flood risk perception, on the other hand, a little effects of flood risk reduction are shown in the results of [CASE 1] to [3] and the expected value of flood risk becomes a little high in the result of [CASE 4]. To perceive a flood risk correctly is important, because that the promotion of flood risk perception may decrease the flood risk in the whole urban area. It is necessary to implement the promotion measure of flood risk perception such as the disaster education, disaster information dissemination and so on.

D. Analysis of changes of land price

The changes of land price cased by flood control works are shown in Figure 7 and the changes of land price caused by the promotion of flood risk perception are shown in Figure 8. To implement a flood control work brings about the tendency for a land price to rise in the area where flood risks that is inundation depths are from 3 to 6m. If a flood risk perception was promoted, a land price falls in the area where flood risks are from 3 to 6m and a land price rises in the area where flood risks are from 1 to 3m. Furthermore, if it becomes optimistic about

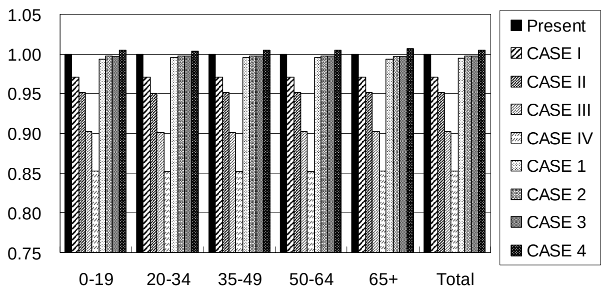

Figure 6. *Expected values of flood risk in the whole Gifu urban area*

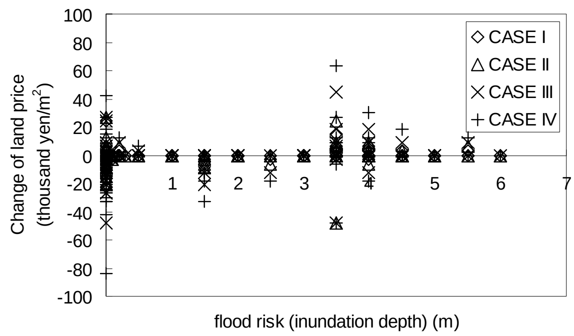

Figure 7. *Changes of land price caused by flood control work*

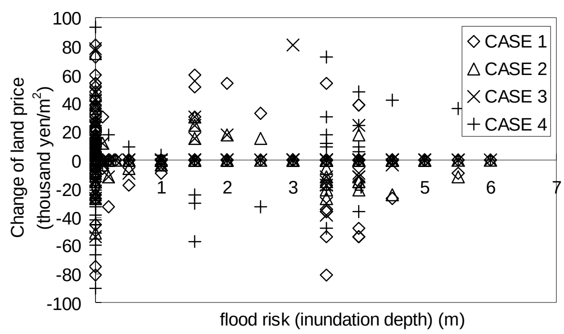

Figure 8. *Changes of land price caused by promotion of flood risk perception*

a flood risk as shown in the result of [CASE 4], a land price will rise in the area where flood risks are from 3 to 6m, and the same tendency as the case of flood control work will be brought about.

E. Analysis of land properties

Figure 9 shows the total amount of land property of each case in the whole Gifu urban area. Although the whole area becomes safe caused by flood control work, the total amount of land property reduces as a flood risk reduces. When the promotion measure of flood risk perception implements, if a flood risk is correctly perceived such as [CASE 1] to [3], the total amount of land property in the whole Gifu urban area will increase. On the other hand, if it becomes optimistic about a flood risk as [CASE 4], the total amount of land property in the whole Gifu urban area will reduce.

If residents take a risk aversion behavior independently according to perceiving a flood risk cased by disaster education etc., the flood in the whole Gifu urban area risk may reduce and the total amount of land property may increase. In addition, the cost of flood risk management is not considered. However, the cost of promotion measures for a flood risk perception is quite cheaper than a flood control work. Therefore, the promotion measure of flood risk perception is efficient, even if it sees from the cost benefit analysis point of view.

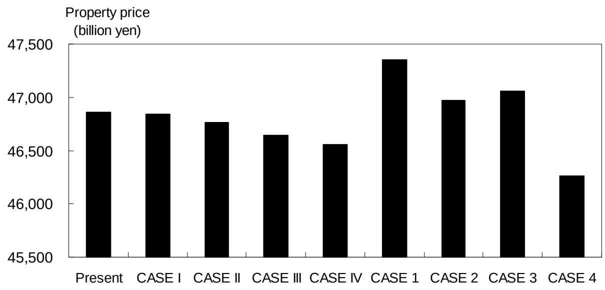

Figure 9. *Total amount of land properties in the whole Gifu urban area*

IV. CONCLUDING REMARKS

In this paper, we analyzed the influence on land use change caused by perceiving the flood risk. Consequently, the meaning of the promotion measure for flood risk perception such as disaster education and information dissemination, etc., was presented. The main conclusions of this paper are described below:

1) To implement the flood control work may increase the amount of location in the area where a flood risk is high, may rise land price, and may reduce the total amount of land property in the whole urban area.
2) If a flood risk is perceived correctly, the amount of location will decrease in the area where a flood risk is high. In this case, although the land price falls, the total amount of land property in the whole urban area may increase on the contrary.
3) The promotion measure of perceiving the flood risk by flood information dissemination and disaster education etc. may be equal or more effective and efficient compared with the flood control works.

In addition, the results in this paper were not confirmed by the real phenomenon and are only some examples of simulation. These need to be checked by analyzing from various viewpoints. Moreover, it is necessary to analyze and also compare the measures, such as land use regulation and promotion system for location change etc. The coordinative research between flood disaster risk management and urban planning is necessary to both sides of practice and theory.

ACKNOWLEDGEMENT

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REFERENCE

- Burton, I., Kates, R. W., and White, G. F. [1993]: Is the Environment Becoming More Hazardous? In the Environment as Hazard, pp.1-30, The Guilford Press, New York.
- Hirokazu TATANO [2005]: Risk Information and Risk Perception: Land Use on the Situation of Existing the Bias of Risk Perception, Hirokazu TATANO and Akiyoshi TAKAGI, *Economic Analysis for Disaster Risk Management*, Keisoshobo, pp.151-172 (in Japanese).
- Shunji MIYAZAWA, Akiyoshi TAKAGI, Takamasa AKIYAMA and Takahito OMORI [2006]：A Cohort-based Location Equilibrium Model with Fuzzy Reasoning and GIS Data, *Infrastructure Planning Review*, Vol.23 (in Japanese) (submitting).