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An Input-output Analysis for Economic Losses of Flood Caused by Global Warming - A Case Study of Japan at the River Basin's Level

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Abstract

Global warming apprehends the risk of flood in lowland area due to sea-level rise. The flood disaster does not only generate the direct damage but also brings about various indirect economic losses especially in large river basin where population and economy are concentrated. Therefore, it is essential to estimate direct and indirect economic effect of flooding at the river basin's level for effective adaptation policy.

This paper identifies economic losses of flood in several major river basins in Japan by industries and regions. First, this paper calculates flooded area due to climate change, based on the IPCC (Intergovernmental Panel on Climate Change) scenario, with the GIS (Geographic Information System)-based analysis. Second, this paper focuses on agriculture and estimates its direct economic losses of flooding. Third, the input-output model with mixed exogenous and endogenous variables is applied to inter-regional input-output tables for the estimation of indirect economic losses.

The results show the differences of potential damage of flood among each river basin and would provide the implication of adaptation policy in terms of economic aspect.

Key words; Flooded area, River basin, GIS, Inter-regional input-output table

1. Introduction

Global warming apprehends the risk of flood in lowland area due to sea-level rise. The IPCC (Intergovernmental Panel on Climate Change) reports sea level may rise from 18 to 59 cm in the end of this century(IPCC, 2007). Especially, flooded area in lower river basin can be expanded by storm surge and tide level in addition to sea-level. Lowland area concentrates large population and it is used variously. These situations imply flood disaster in lower river basin may bring about

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huge economic damage directly and indirectly.

There are two responses to climate change: mitigation by reducing greenhouse-gas (GHG) emissions and enhancing sinks, and adaptation to the impacts of climate change. Both mitigation and adaptation seek to avoid the potential damage and to support the sustainable development of present and future generation. Recently, adaptation is receiving more attention as a critical part of climate change along with mitigation.

In discussing adaptation policies against flood disaster, it is necessary to estimate its scale more quantitatively as its precondition. This paper addresses economic damage in addition to simulating flooded area with regard to flooding risk attributed to global warming. The flood disaster does not only generate the direct damage but also brings about various indirect economic losses since many activities are interlinked and the spatial divisions have been advanced. Therefore, it is essential to evaluate direct and indirect economic effects of flood due to global warming for effective countermeasures.

This paper focuses on agriculture, which directly utilizes land as a production factor, and calculates direct economic losses in agricultural sector due to flooding. In addition, we estimate indirect economic losses derived from direct ones in agricultural sector with input-output analysis, considering the transactions among regions and industries.

This paper investigates flood disaster at the river basin’s level in Japan. A lot of lowland which are exposed to flooding risk corresponds to lower river basin. Moreover, economic structures such as industrial accumulation or industrial linkage tend to be formed at the river basin’s level because many factors, such as economy, population, and farmland, concentrates in lower river basin. It is expected that characteristics of flood disaster largely differs at the river basin’s level due to geographical features or economic activities. Therefore, it is significant to consider adaptation policies at the river basin’s level against flooding

The remainder of the paper is structured as follows. Section 2 explains the methodology for identifying the flooded area and direct economic losses of agricultural sector. Section 3 explains the input-output model for evaluating indirect economic impact. Section 4 shows and discuss the results. The final section includes concluding remarks.

2. Calculation of flooded area and direct economic losses

Potential flooded area and its land use are simulated by Kuwahara et al. (2008). Kuwahara et al. (2008) constructs the GIS(Geographic Information System) dataset of 10 major rivers in Japan and assumes that there would be 59cm sea-level rise at the end of this century based on the scenario of IPCC (2007) and the effect of storm surge and tide level. It then employs the level flood method to identify the flooded area. This method detects flooded area in the GIS dataset with the input data of altitude above sea level and physiognomy effect. Figure 1 shows the detection process in the level flood method.

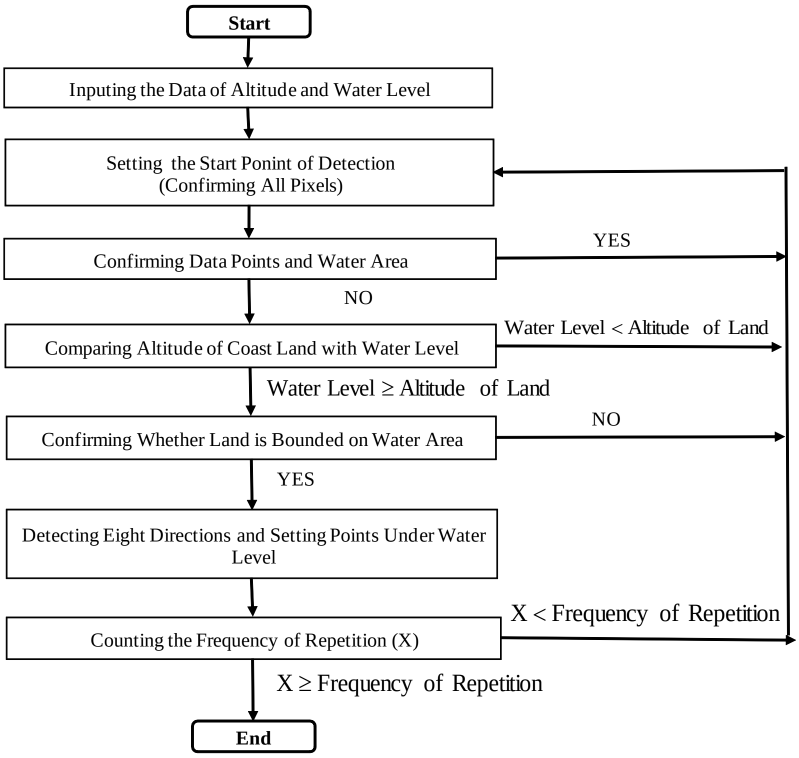

Figure 1 Flow Chart of level flood method

This paper picks up four rivers with largest flooded area in farmland out of ten rivers in Japan, which are analyzed by Kuwahara et al. (2008). Figure 2 shows the locations of the four investigated rivers and their surrounding prefectures in Japan. This paper primarily calculates direct economic losses in agriculture, and secondarily estimates indirect losses they bring about among industries and regions.

We regard the monetary output which the flooded farmland is supposed to pay as the direct economic losses in agricultural sector. This paper identifies output and farmland area for each agricultural product at smaller regional levels from agricultural census, and calculates output per area (million yen/ha) for each farmland type in smaller regions. Using the data of output per area, we are able to convert flooded area in farmland estimated by the GIS method into direct economic losses.

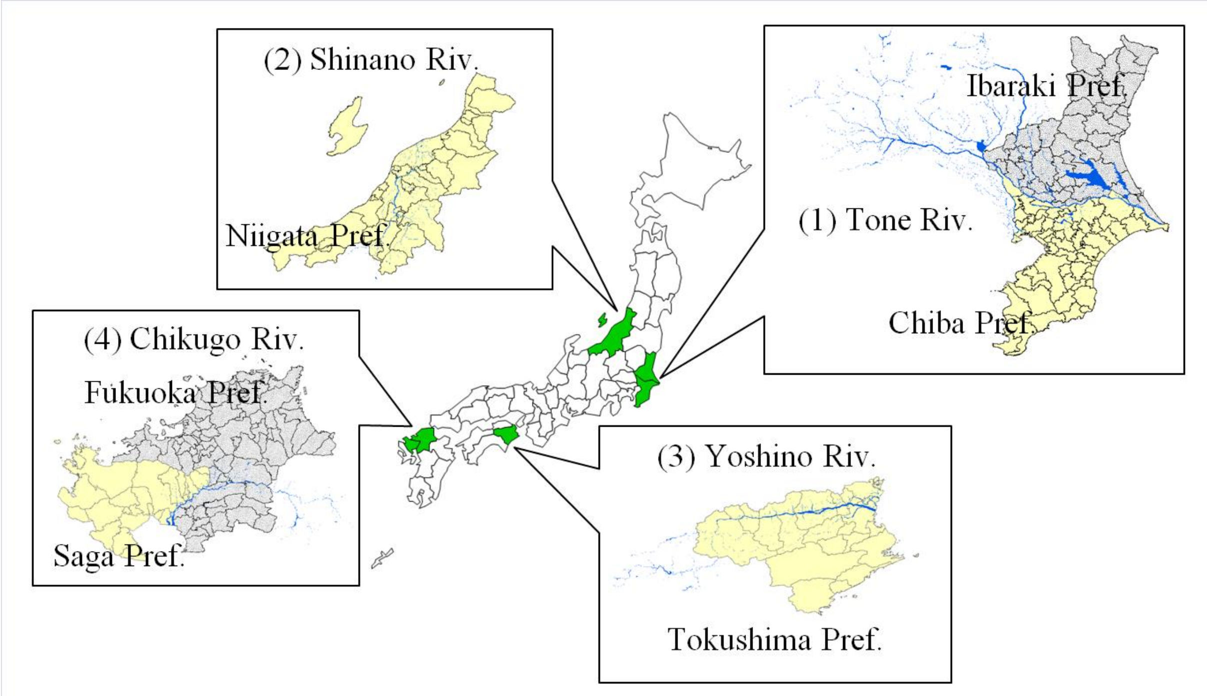

Figure 2 Locations of investigated four rivers and prefectures including their flooded area

3. Input-output method for indirect economic losses

The input-output analysis enables us to estimate indirect economic effects with taking economic repercussion among industries or regions into account. An ordinal demand-side input-output model, developed by W. Leontief (Leontief 1966 etc.), identifies economic repercussion by regarding final demand such as household consumption or private investment as exogenous variables. It means that the output in each industry is determined by the change of specific final demand as exogenous variables.

On the other hand, flooding would have significant influence on certain fields such as decrease in agricultural productivity and capacity of firms. Direct effect lead by flooding is considered as the change (decrease) in outputs in specific industries. Therefore, it is appropriate to regard the outputs in the particular sectors damaged directly as exogenous variables when considering indirect effect of natural disasters such as flooding. Here, input-output model with mixed exogenous and endogenous variables was applied to estimate the economic impact of potential flooding(see, e.g., Tiebout, 1969; Miller and Blair, 1985). The model with mixed variables has been employed by several literatures; for example, Davis and Salkin (1984) and Jiang et al. (2005) employ the model to analyze the constraints of water supply.

The model with mixed variables is explained as follows. To begin with, we assume balance equation of basic input-output with no foreign trade:

$$\mathbf{x}=\mathbf{A}\mathbf{x}+\mathbf{f}$$
$$\Leftrightarrow\ (\mathbf{I}-\mathbf{A})\mathbf{x}=\mathbf{f}, \tag{1}$$

where **x** is output vector, **A** is technical coefficient matrix, and **f** is final demand vector.

When we assume that there are three sectors and the output in third sector (x_3) is an exogenous variable, equation (1) can be given as follows:

$$(\mathbf{I}-\mathbf{A})\mathbf{x}=\mathbf{f}$$

$$\Leftrightarrow \begin{cases}(1-a_{11})x_1-a_{12}x_2+0f_3=f_1+0f_2+a_{13}x_3\\ -a_{21}x_1+(1-a_{22})x_2+0f_3=0f_1+f_2+a_{23}x_3\\ -a_{31}x_1-a_{32}x_2-f_3=0f_1+0f_2-(1-a_{33})x_3\end{cases}$$

$$\Leftrightarrow \begin{bmatrix}(1-a_{11}) & -a_{12} & 0\\ -a_{21} & (1-a_{22}) & 0\\ -a_{31} & -a_{32} & -1\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ f_3\end{bmatrix}=\begin{bmatrix}1 & 0 & a_{13}\\ 0 & 1 & a_{23}\\ 0 & 0 & -(1-a_{33})\end{bmatrix}\begin{bmatrix}f_1\\ f_2\\ x_3\end{bmatrix}$$

$$\Leftrightarrow \begin{bmatrix}(1-a_{11}) & -a_{12} & 0\\ -a_{21} & (1-a_{22}) & 0\\ -a_{31} & -a_{32} & -1\end{bmatrix}^{-1}\begin{bmatrix}1 & 0 & a_{13}\\ 0 & 1 & a_{23}\\ 0 & 0 & -(1-a_{33})\end{bmatrix}\begin{bmatrix}f_1\\ f_2\\ x_3\end{bmatrix}=\begin{bmatrix}x_1\\ x_2\\ f_3\end{bmatrix}. \tag{2}$$

Given that x_3 changes as denoted by $\Delta\bar{x}_3$, its final demand and the other outputs, Δf_3, Δx_1, and Δx_2, are endogenously determined as in equation (3):

$$\begin{bmatrix}(1-a_{11}) & -a_{12} & 0\\ -a_{21} & (1-a_{22}) & 0\\ -a_{31} & -a_{32} & -1\end{bmatrix}^{-1}\begin{bmatrix}1 & 0 & a_{13}\\ 0 & 1 & a_{23}\\ 0 & 0 & -(1-a_{33})\end{bmatrix}\begin{bmatrix}0\\ 0\\ \Delta\bar{x}_3\end{bmatrix}=\begin{bmatrix}\Delta x_1\\ \Delta x_2\\ \Delta f_3\end{bmatrix}. \tag{3}$$

This paper focuses on decrease of output in agricultural sectors as direct economic losses caused by flooding, and estimates indirect economic losses among industries and regions derived from their direct losses by using equation (3). The decrease of agricultural output is represented by $\Delta\bar{x}_3$ in equation (3).

This paper applies the model represented as equation (3) to inter-regional input-output tables in order to distinguish indirect economic loss among regions as well as industries. Inter-regional tables are constructed according to flooded area at the river basin's level.

Since each prefectural office in Japan publishes intra-regional table for their own prefecture, inter-regional tables can be made so that they can be distinguished between regions with and without flooded area at the prefectural level. We construct four inter-regional tables in order to estimate indirect economic losses for four rivers. Table 1 shows the details of inter-prefectural tables corresponding to each river (see Figure 2 with regard to the location of investigated rivers and prefectures including their flooded area in Japan). These inter-regional tables in Table 1 have exogenous output in agricultural sectors in the prefectures including flooded area and endogenous outputs in other sectors.

Table 1 Details of inter-regional input-output tables

River[1]	Prefecture[1] of Flooded Area	Constructed Inter-regional Table	
		The Number of Regions[2]	The Number of Sectors[3]
(1) Tone	Chiba, Ibaraki	3	104
(2) Shinano	Niigata	2	168
(3) Yoshino	Tokushima	2	104
(4) Chikugo	Fukuoka, Saga	3	103

Note: 1) See Figure 2 about their locations.
2) They includes prefectures of both flooded area and non-flooded area.
3) They are the most detailed classifications in available data.

4. Results

Table 2 shows the result of flooded area calculated by the GIS method, and Table 3 shows direct economic losses based on flooded farmland. The Tone River has the largest total flooded area among the four rivers as in Table 2. It is mainly because the Tone River has the largest basin area and the second longest trunk river route in Japan. On the other hand, it is notable that the Shinano River has the smallest total flooded area, although it is one of the largest river with the third largest basin area and the longest trunk river route in Japan. It is mainly because it has the smallest lowland area. Notably, the Chikugo River has the second largest total flooded area following the Tone River, although it is the smallest in terms of both basin area and length trunk. Moreover, the flooded area in farmland in the Chikugo River accounts for about 70% of all, implying that the flood disaster in agriculture could be serious.

Table 3 indicates direct economic losses in agriculture which are calculated from flooded farmland. They results in the decrease of monetary output in agriculture which is expected to be made in flooded farmland. Direct economic losses in each river do not always have the same trend of their flooded area because the losses per area largely differ among rivers, prefectures, and field type. The differences reflect on economic terms such as cultivated agricultural products and their prices, and natural conditions such as fertility and weather.

Although the area in “rice field” is much larger than in “other field” in each river, their differences become smaller when they are compared with economic losses. It is because the losses per area in “other field” is much larger than in “rice field”. Especially, in the Yoshino River, direct economic losses in “other field” are much larger than in “rice field” in contrast to their flooded area.

Table 2 Land use of flooded area

(km^2)

	(1) Tone Riv.	(2) Shinano Riv.	(3) Yoshino Riv.	(4) Chikugo Riv.
Rice Field	181.70	21.19	41.34	196.69
Other Field	4.59	1.92	9.28	2.47
Total Farmland	186.29	23.11	50.62	199.16
Forest	0.78	0.00	1.06	0.15
Wasteland	3.04	0.17	0.03	0.50
Building Site	19.98	27.52	21.87	50.76
Traffic Site	1.42	4.72	1.50	0.27
Other Artificial Site	6.05	7.93	8.28	3.82
Freshwater	240.58	8.02	23.46	30.70
Seashore	0.02	0.00	0.17	0.00
Seawater	0.04	0.00	0.11	0.00
Golf Course	0.88	0.00	0.15	0.76
Total	459.08	71.47	107.25	286.12

Table 3 Direct economic losses due to flooding in agricultural sectors

(Million yen)

	(1) Tone Riv.			(2) Shinano Riv.	(3) Yoshino Riv.	(4) Chikugo Riv.		
	Chiba Pref.	Ibaraki Pref.	Total	Niigata Pref.	Tokushima Pref.	Fukuoka Pref.	Saga Pref.	Total
Rice Field	6060 (1.22)	14209 (1.08)	20269 (1.12)	2919 (1.38)	2037 (0.49)	5257 (0.65)	11289 (0.97)	16545 (0.84)
Other Field	233 (3.84)	1724 (4.33)	1956 (4.26)	1130 (5.89)	12222 (13.17)	1915 (17.09)	1712 (12.69)	3628 (14.69)
Total	6293 (1.25)	15933 (1.17)	22225 (1.19)	4050 (1.75)	14260 (2.82)	7172 (0.88)	13001 (1.11)	20173 (1.01)

Note: Figures in parentheses indicate direct losses per flooded area of 1ha (Million yen/ha).

Next, the indirect economic losses are investigated. Table 4 shows the total economic losses which consist of direct and indirect losses. Economic losses in Table 4 are distinguished by industries and whether the prefectures may include flooded area. The Tone River has the largest total losses in the four rivers, 38.5 billion yen, followed by The Chikugo River (35.6 billion yen), the Yoshino River (24.9 billion yen), and the Shinano River (6.7 billion yen). On the other hand, the Chikugo River has the largest ratio of total losses to indirect ones, 1.76, followed by the Yoshino River (1.75), the Tone River (1.73), and the Shinano River (1.66).

We focus more on indirect losses in Figure 3. Figure 3 indicates the composition of indirect losses among industries and regions. The ratio of the indirect losses in the rest of Japan to the total indirect ones differs from 42.7 (the Chikugo River) to 58.1% (the Yoshino River) among four rivers. It is common in each river that more indirect losses are generated in secondary and tertiary industry than in primary industry including agriculture sector, and secondary industry has more indirect losses than in the rest of Japan than in flooded prefectures and tertiary industry has the opposite situation. Table 4 and Figure 3 indicates that the scale of indirect losses is not so small compared to direct ones because indirect losses can extend beyond industries and regions.

Table 4 Direct and indirect economic losses among industries and regions

(Million yen)

		(1) Tone Riv.			(2) Shinano Riv.		
		Flooded Prefecture	The Rest of Japan	Total	Flooded Prefecture	The Rest of Japan	Total
Primary Industry	Agriculture	22225 (100)	271 (1.2)	22497 (101.2)	4050 (100)	42 (1.0)	4091 (101.0)
	Other Primary Industry	916 (4.1)	103 (0.5)	1019 (4.6)	306 (7.6)	19 (0.5)	325 (8.0)
Secondary Industry	Light Industries	369 (1.7)	1169 (5.3)	1537 (6.9)	49 (1.2)	131 (3.2)	181 (4.5)
	Heavy Industries	1441 (6.5)	3696 (16.6)	5137 (23.1)	264 (6.5)	571 (14.1)	835 (20.6)
	Other Secondary Industry	409 (1.8)	277 (1.2)	685 (3.1)	43 (1.1)	55 (1.4)	98 (2.4)
Tertiary Industry	Transportation	1259 (5.7)	449 (2.0)	1708 (7.7)	197 (4.9)	60 (1.5)	257 (6.4)
	Service	736 (3.3)	825 (3.7)	1561 (7.0)	132 (3.2)	120 (3.0)	251 (6.2)
	Other Tertiary Industry	2308 (10.4)	2091 (9.4)	4399 (19.8)	409 (10.1)	277 (6.8)	686 (16.9)
Total		29662 (133.5)	8882 (40.0)	38544 (173.4)	5449 (134.5)	1275 (31.5)	6724 (166.0)

		(3) Yoshino Riv.			(4) Chikugo Riv.		
		Flooded Prefecture	The Rest of Japan	Total	Flooded Prefecture	The Rest of Japan	Total
Primary Industry	Agriculture	14260 (100)	153 (1.1)	14413 (101.1)	20173 (100)	216 (1.1)	20389 (101.1)
	Other Primary Industry	879 (6.2)	59 (0.4)	938 (6.6)	1156 (5.7)	122 (0.6)	1277 (6.3)
Secondary Industry	Light Industries	330 (2.3)	582 (4.1)	912 (6.4)	485 (2.4)	846 (4.2)	1330 (6.6)
	Heavy Industries	513 (3.6)	2665 (18.7)	3179 (22.3)	1516 (7.5)	3217 (15.9)	4733 (23.5)
	Other Secondary Industry	124 (0.9)	277 (1.9)	400 (2.8)	213 (1.1)	337 (1.7)	551 (2.7)
Tertiary Industry	Transportation	901 (6.3)	340 (2.4)	1242 (8.7)	1162 (5.8)	287 (1.4)	1450 (7.2)
	Service	444 (3.1)	664 (4.7)	1109 (7.8)	938 (4.6)	474 (2.3)	1411 (7.0)
	Other Tertiary Industry	1285 (9.0)	1456 (10.2)	2741 (19.2)	3354 (16.6)	1079 (5.3)	4433 (22.0)
Total		18737 (131.4)	6197 (43.5)	24934 (174.9)	28997 (143.7)	6578 (32.6)	35575 (176.3)

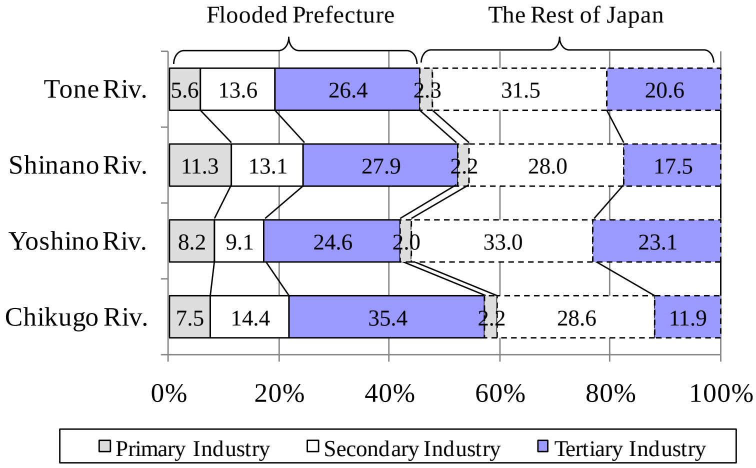

Figure 3 Differences of composition of indirect losses among four rivers

5. Conclusion

This paper estimate economic losses of flood caused by global warming at the river basin's level in Japan. In estimating flooded area, we employ level flood method with the GIS dataset by assuming that 59cm sea-level rise at the end of this century and by including the effect of storm surge and tide level. In terms of economic losses, we focus on direct losses in agriculture and estimate their indirect losses using inter-regional model which has exogenous directly damaged output in agriculture.

It is found that (1) direct losses per area differ from 1.01 to 2.82 million yen/ha among four rivers reflecting the differences of cultivated agricultural products, their prices, the degree of fertility, and weather condition, (2) the total losses (direct and indirect losses) are as 1.66 to 1.76 times large as direct ones implying the scale of indirect losses is not so small as that of direct ones, (3) more indirect losses would be generated in secondary and tertiary industry than primary industry including agricultural sector, and (4) the ratio of indirect losses in the outside area[1] to total indirect ones differs from 42.7 to 58.1% among four rivers.

Our analyses reveal the differences of direct economic loses per area, and the scale and scope where indirect losses extend beyond industries and regions at the river basin's level. The results imply validity in adaptation policy at the river basin's level against flood disaster.

We must refer to further remaining issues in this paper. Although we estimate flooded area with the GIS method by considering only the altitude above sea level and physiognomy effect, it is also necessary to allow for the distribution of defense faculties such as embankment and the roughness of different land for more sophistication. Moreover, it is required to count not only sea-level rise but also the change of precipitation to predict the flood disaster caused by climate change. In regard to estimating economic losses, we assume current economic structure for the scenario of

[1] It means prefectures which do not include flooded area (the rest of Japan in Figure 2).

sea-level rise in the end of this century(i.e., input-output tables in 2000 year are uses).

In the future, this approach enables us to develop inter-regional input-output model toward smaller district more corresponding to the flooded area, and to apply to other sectors as well as agriculture. Finally, for the comprehensive adaptation policy, it is essential to assess the damage of non-economic aspect such as environment and ecosystem inherent to each river basin.

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