# Chapter 2

# Innovative Methodology for a Regional Assessment of Economic Losses and Damage Caused by Natural Disasters

Yumi Shiomi, Takahiro Ono, and Seiichiro Fukushima

December 2019

**This chapter should be cited as**

Shiomi, Y., T. Ono and S. Fukushima (2019), 'Innovative Methodology for a Regional Assessment of Economic Losses and Damage Caused by Natural ', in Anbumozhi, V., M. Breiling, and V. Reddy (eds.), *Towards a Resilient ASEAN Volume 1: Disasters, Climate Change, and Food Security: Supporting ASEAN Resilience*. Jakarta, Indonesia: Economic Research Institute for ASEAN and East Asia, pp. 17-36.

CHAPTER 2

# Innovative Methodology for a Regional Assessment of Economic Losses and Damage Caused by Natural Disasters

**Yumi Shiomi**
Asian Disaster Reduction Center (ADRC), Kobe, Japan

**Takahiro Ono**
Mitsubishi Insurance Disaster Reduction Engineering Group, Tokyo, Japan

**Seiichiro Fukushima**
Electric Power Services Co., Ltd., Tokyo, Japan

## 2.1 Introduction

Asia is exposed to natural hazards. It has the largest share of all regions in terms of disaster occurrence (39%), the number of people killed (61%) and affected (89%), and economic damage (48%) for 1986–2015 (Asian Disaster Reduction Center, 2016). In 2015 alone, Asia incurred more than $45 billion in economic damages and even higher indirect losses (United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), 2016). The Association of Southeast Asian Nations (ASEAN) region is the most prone to disasters in the world (Sawada and Oum, 2012). In recent years, it has suffered devastating disaster events such as the Indian Ocean tsunami in 2004, the Yogyakarta earthquake in 2006, the Myanmar cyclone in 2008, Typhoon Ketsana in 2009, the Thai floods in 2011, Typhoon Haiyan in 2013, and so on. These disasters – including earthquakes, tsunamis, storms, and floods – have direct and indirect cross-border impacts.

Natural hazards and their effects are transboundary by nature, which puts the ASEAN region in a unique position to confront the development challenges presented by these phenomena (ASEAN, 2016).

Focusing on disaster type, the ASEAN region has a variety of disaster risks: climatological, geographical, hydrological, and meteorological. Table 2.1 shows the disaster impacts of the ASEAN member countries by disaster type for 1986–2015.

**Table 2.1:** Disaster Types in ASEAN, 1986–2015

| Disaster type | Occurrence | Dead and missing people | Affected people | Amount of damage ($'000) |
|---|---|---|---|---|
| Drought | 18 (2.4%) | 11 (0.0%) | 28,889,289 (12.3%) | 1,401,272 (1.4%) |
| Earthquake | 59 (8.0%) | 184,386 (51.4%) | 11,377,256 (4.8%) | 13,024,057 (13.4%) |
| Epidemic | 34 (4.6%) | 2,568 (0.7%) | 325,826 (0.1%) | - (0.0%) |
| Extreme temperature | 1 (0.1%) | 63 (0.0%) | 1,000,000 (0.4%) | - (0.0%) |
| Flood | 337 (45.9%) | 9,617 (2.7%) | 85,480,497 (36.4%) | 55,646,645 (57.3%) |
| Landslide | 59 (8.0%) | 3,013 (0.8%) | 700,091 (0.3%) | 69,685 (0.1%) |
| Storm | 194 (26.4%) | 158,968 (44.3%) | 105,978,977 (45.1%) | 25,768,266 (26.5%) |
| Volcanic activity | 26 (3.5%) | 367 (0.1%) | 720,400 (0.3%) | 188,580 (0.2%) |
| Wildfire | 7 (1.0%) | 19 (0.0%) | 410,064 (0.2%) | 1,014,000 (1.0%) |
| **Total** | **735 (100.0%)** | **359,012 (100.0%)** | **234,882,400 (100.0%)** | **97,112,505 (100.0%)** |

ASEAN = Association of Southeast Asian Nations.

Source: Asian Disaster Reduction Center (2016).

While floods and storms occupy the largest shares in terms of occurrence, earthquakes (and subsequent tsunamis) and storms comprise more than 90% of fatalities. As for the number of people affected and the amount of damage, floods and storms again occupy the majority share amongst all disaster types. Overall, this tendency implies that the ASEAN region is vulnerable to meteorological and hydrological disasters, followed by geophysical ones.

With the increasing attention to and need for disaster risk reduction and management in recent decades, a significant amount of research has been carried out to examine disaster risks and economic impacts caused by natural disasters. This includes the statistical/econometric model, computable general equilibrium models, and input–output (I–O) analysis.

The World Bank et al. (2010) conducted a risk assessment of ASEAN countries by reviewing the existing hazard, vulnerability, and economic loss data at the country level. It estimated the economic vulnerability of each country in terms of the likely economic losses that an event with a 200-year return period would cause as a percentage of that country's gross domestic product (GDP at purchasing power parity). It ranked the economic vulnerability in descending order: Myanmar, the Lao People's Democratic Republic, Indonesia, Cambodia, Viet Nam, the Philippines, Thailand, and Malaysia.

The I–O model has been widely used in various disaster impact analyses. Kajitani, Yamano, and Tatano (2005) estimated the economic loss caused by the Chuetsu earthquake in 2005 with the multiregional I–O model, while van der Veen and Logtmeijer (2005) applied the model to simulate large-scale flooding in the Netherlands.

Fukushima, Hayashi, and Yashiro (2009) and Hayashi, Fukushima, and Yashiro (2009) focused on the linkage between business and the local economy, and suggested a methodology to estimate the indirect damage to business from the economic damage of an affected area in the case of a large-scale earthquake. They employed the loss of GDP as an index to measure the economic loss of the region by applying a model developed by the Central Disaster Prevention Council of Japan in 2008. That model has been used for various analyses, e.g. Japan's Ministry of Land, Infrastructure, Transport and Tourism (2013) applied its methodology to estimate damage from flooding.

Comparative analyses of such models identify both advantages and disadvantages in each model (Okuyama, 2009; Kelly, 2015). The I–O model has strength in its simple structure, detailed inter-industry linkage, wide range of analytical techniques available, and ability to be easily modified and integrated with other models, while its weaknesses are its linear structure, rigid coefficients, lack of supply capacity constraints, absence of response to price changes, and overestimation of impact (Okuyama, 2009).

In surveying the intrinsic complexity of disaster-prone ASEAN countries, this paper employs the I–O model to examine economic losses and damages in the region considering the applicability and adaptability of the model and data availability – it can show the ripple effects from a disaster-affected area to a country and then to other countries and the region.

The objective of this chapter is to introduce a model for an overall assessment of economic losses and damages caused by natural disasters at the local, national, and regional levels in the ASEAN region.

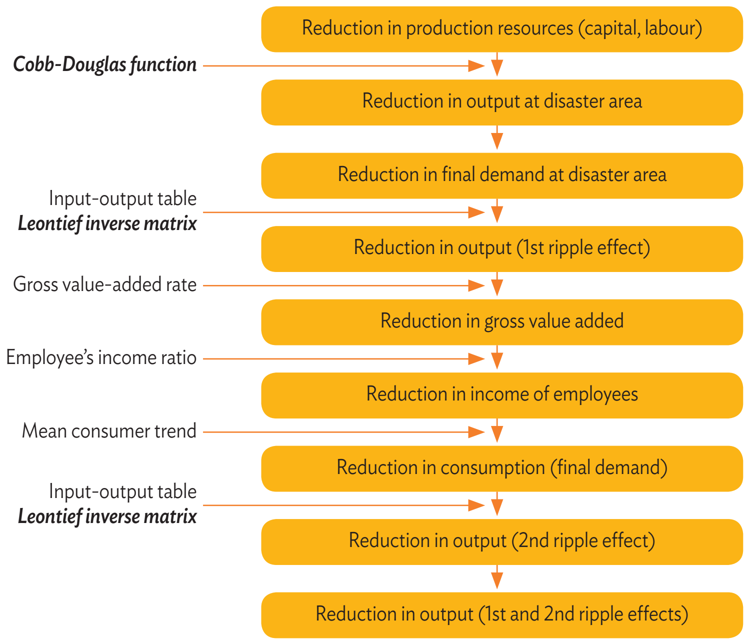
## 2.2 Establishment of Methodology to Evaluate Economic Loss at the Regional Level

This paper employs the loss of GDP as an index to measure the economic loss of the region concerned. Section 2.1 introduces the methodology based on that of the Central Disaster Prevention Council of Japan, while section 2.2 explains the economic loss of enterprises.

### 2.2.1 Methodology to Evaluate Economic Loss of Region

Figure 2.1 shows the flowchart of economic loss evaluation.

**Figure 2.1: Flowchart to Obtain Economic Loss of Region**




Source: Fukushima, Hayashi, and Yashiro (2009).

#### (1) Reduction in Final Demand at Disaster Area

It is assumed that the reduction in final demand at the disaster area is equal to that of the regional output. The reduction in regional output $\Delta GDP$ for each industry is estimated by the following equation:

$$\Delta GDP = GDP_0 - GDP_1 = \left(1 - \frac{GDP_1}{GDP_0}\right) GDP_0$$

where $GDP_0$ is the output during a normal period and $GDP_1$ is the output after a disaster. If the regional output is expressed by the Cobb-Douglas function, which is $Y = A \cdot K^{\alpha} \cdot L^{1-\alpha}$, the following equation is derived:

$$\Delta GDP = \left(1 - \frac{A \cdot {K_1}^{\alpha} \cdot {L_1}^{1-\alpha}}{A \cdot {K_0}^{\alpha} \cdot {L_0}^{1-\alpha}}\right) GDP_0 = \left[1 - \left(1 - \frac{k}{K_0}\right)^{\alpha} \cdot \left(1 - \frac{l}{L_0}\right)^{1-\alpha}\right] GDP_0$$

$$k = K_0 - K_1, \; l = L_0 - L_1$$

where $K_0$ and $K_1$ are the capital stock during a normal period and after a disaster; $L_0$ and $L_1$ are the labour input during a normal period and after a disaster; and $A$ and $\alpha$ are the parameters defined for each industry. The above equation shows that the ratios $k/K_0$ and $l/L_0$ give $\Delta GDP$ using $k$ and $l$, which are the lost capital stock and the lost labour input after disaster.

### (2) Estimation of Loss Ratio of Capital Stock

The loss ratio of capital stock in a disaster area $R_K(= k/K_0)$ is given by the following equation:

$$R_K = \frac{1}{N}\sum_{i=1}^{N} r_{Ki}$$

where $r_{Ki}$ is the loss ratio of capital stock of mesh $i$ in the area and $N$ is the number of the mesh. The loss ratio of capital stock $r_{Ki}$ is given by the following equation:

$$r_{Ki} = z \cdot \frac{n_{RCi} + n_{RMi} + n_{SCi} + n_{SMi}}{n_{Ri} + n_{Si}} = z \cdot \left[\frac{n_{Ri}}{n_{Ri} + n_{Si}} f_{RM}(x_i) + \frac{n_{Si}}{n_{Ri} + n_{Si}} f_{SM}(x_i)\right]$$

where $n_{RCi}$ and $n_{RMi}$ are the number of collapsed and partially collapsed reinforced concrete non-residential buildings in mesh $i$, and $n_{SCi}$ and $n_{SMi}$ are those of steel non-residential buildings; $n_{Ri}$ and $n_{Si}$ are the numbers of reinforced concrete non-residential and steel buildings; $f_{RM}(x_i)$ and $f_{SM}(x_i)$ are the conditional failure probabilities of reinforced concrete and steel non-residential buildings in mesh $i$, given ground motion intensity of $x_i$; and $z$ is the factor, which is 0.706 for manufacturers and 0.732 for other industries.

### (3) Estimation of Loss Ratio of Labour Input

The loss ratio of the labour input in the disaster area $R_L\,(=l/L_0)$ is given by the following equation:

$$R_L = \frac{1}{N}\sum_{i=1}^{N} r_{Li}$$

where $r_{Li}$ is the loss ratio of the labour input of mesh $i$ in the area and $N$ is the number of the mesh. The loss ratio of the labour input $r_{Li}$ is given by the following equation:

$$r_{Li} = r_{Di} + r_F = \frac{n_{Di}}{n_{Pi}} + r_F$$

where $r_{Di}$ is the casualty rate of mesh $i$; $r_F$ is the unemployment ratio, which is constant (=0.036) for the area of ground motion intensity of 5.5 or greater on the scale of the Japan Meteorological Agency; and $n_{Di}$ and $n_{Pi}$ are the number of deaths and daytime population of mesh $i$. Using the number of collapsed wooden residential housings $n_{WCi}$ as a parameter, $n_{Di}$ is approximately given by the following equation:

$$n_{Di} = 0.06875 \cdot n_{WCi} = 0.06875 \cdot f_{WC}(x_i) \cdot n_{Wi}$$

where $f_{WC}(x_i)$ is the conditional failure probabilities of wooden residential housings in mesh $i$, given ground motion intensity of $x_i$; and $n_{Wi}$ is the number of wooden residential housings in mesh $i$.

### (4) Reduction in Output (1st Ripple Effect)

Let $\Delta\mathbf{F}_1$ be the vector consisting of $\Delta F(=\Delta GDP)$, which is the reduction in final demand for each industry. The first step of the ripple effect is given as $\Delta\mathbf{X}_1(1) = \Delta\mathbf{F}_1\,(=\Delta\mathbf{GDP})$. Next, the production of raw material $\Delta\mathbf{X}_1(2)$ necessary for the production of $\Delta\mathbf{X}_1(1)$ is stopped. $\Delta\mathbf{X}_1(2)$ is given by the following equation:

$$\Delta\mathbf{X}_1(2) = \mathbf{A}\cdot\Delta\mathbf{X}_1(1) = \mathbf{A}\cdot\Delta\mathbf{F}_1$$

where $\mathbf{A}$ is the input coefficient matrix derived from the I–O table, whose component $a_{ij}$ is the amount of item $i$ to produce item $j$ of unity.

Further, $\Delta\mathbf{X}_1(3)$ necessary for the production of $\Delta\mathbf{X}_1(2)$ is referred as follows:

$$\Delta\mathbf{X}_1(3) = \mathbf{A}\cdot\Delta\mathbf{X}_1(2) = \mathbf{A}^2\cdot\Delta\mathbf{F}_1$$

The same ripple effect is repeated, so that the final reduction in output $\Delta\mathbf{X}_1$ is given by the following equation:

$$\Delta\mathbf{X}_1 = \Delta\mathbf{F}_1 + \mathbf{A}\cdot\Delta\mathbf{F}_1 + \mathbf{A}^2\cdot\Delta\mathbf{F}_1 + \cdots = (\mathbf{I}-\mathbf{A})^{-1}\cdot\Delta\mathbf{F}_1$$

The matrix $(\mathbf{I}-\mathbf{A})^{-1}$ is called the Leontief inverse matrix, where $\mathbf{I}$ is the unit matrix.

### (5) Reduction in Output (2nd Ripple Effect)

As illustrated in Figure 2.1-1, the reduction in output from the viewpoint of reduction in income is called the second ripple effect. The reduction in consumption $\Delta\mathbf{F}_2$ due to the second ripple effect is given by the following equation:

$$\Delta\mathbf{F}_2 = \mathbf{f}_1\cdot\mathbf{f}_2\cdot\mathbf{f}_3\cdot\Delta\mathbf{X}_1$$

where $\mathbf{f}_1$ is the factor expressing the reduction in gross value added, $\mathbf{f}_2$ is the factor expressing the reduction in employees' income, and $\mathbf{f}_3$ is the factor expressing the trend of consumers.

By multiplying the Leontief inverse matrix to $\Delta\mathbf{F}_2$, the reduction in output $\Delta\mathbf{X}_2$ is given by the following equation:

$$\Delta\mathbf{X}_2 = (\mathbf{I}-\mathbf{A})^{-1}\cdot\Delta\mathbf{F}_2$$

## 2.2.2 Methodology to Evaluate Economic Loss of Enterprises

It is an important point whether the production area and/or consumption area is included in the disaster area. Table 2.2 shows the economic loss for each combination of production and consumption areas. Direct loss, of course, occurs only where the production area is in the disaster area.

**Table 2.2: Categorisation of Economic Loss of Enterprises**

| | | Consumption area | |
|---|---|---|---|
| | | **Within disaster area** | **Outside disaster area** |
| Production area | Within disaster area | The maximum value of the following:<br>• the reduction in sales caused by the reduction in production<br>• the reduction in sales caused by the reduction in consumption | Economic loss is the reduction in sales caused by the reduction in production. |
| | Outside disaster area | Economic loss is the reduction in sales caused by the reduction in consumption. | No economic loss occurs. |

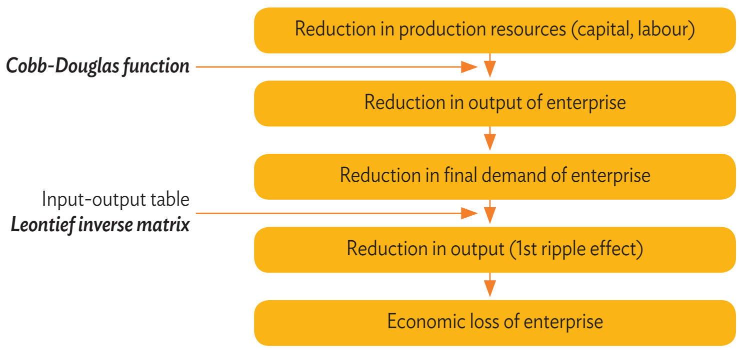
Source: Fukushima, Hayashi, and Yashiro (2009).

## (1) Economic Loss Where the Production Area is in the Disaster Area

Where the production area is in the disaster area and the consumption area is not, the economic loss of enterprises is evaluated as the reduction in sales due to the reduction in production, as shown in Figure 2.2.

To realise the flowchart in Figure 2.2, it is necessary to evaluate the reductions in capital and labour. Capital is estimated by disaster simulation for the enterprise's capital, and labour is estimated by disaster simulation for labour, as illustrated before.

**Figure2.2: Flowchart to Obtain the Economic Loss of Enterprises Where the Production Area is in the Disaster Area**



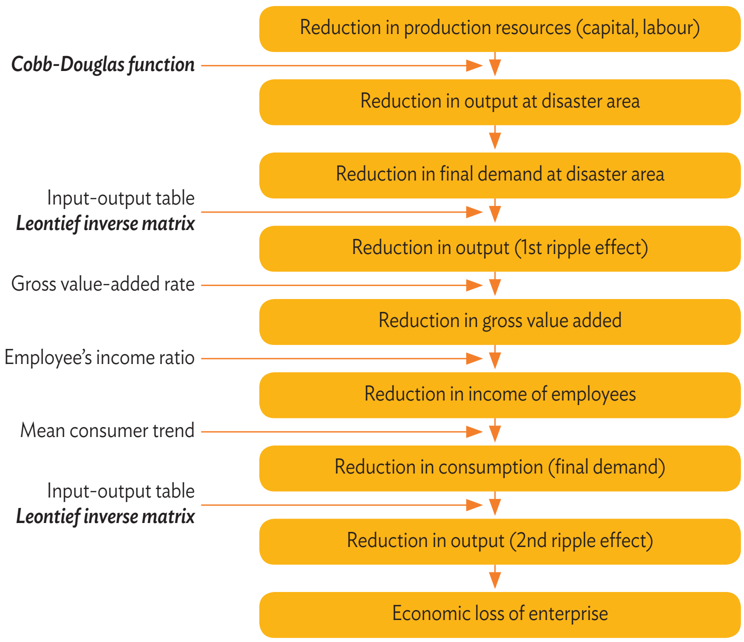

Source: Fukushima, Hayashi, and Yashiro (2009).

### (2) Economic Loss Where the Consumption Area Is in the Disaster Area

Where the consumption area is in the disaster area and the production area is not, the economic loss of enterprises is evaluated as the reduction in sales due to the reduction in consumption, as shown in Figure 2.3.

Figure 2.3 is identical to Figure 2.2 for the evaluation of economic loss at the regional level. However, the reduction in output by the first ripple effect is not for the enterprises concerned, but those in the disaster area. Therefore, the reduction in output is given as the reduction in output by the second ripple effect. The first ripple effect is considered a condition to calculate the second ripple effect.

**Figure 2.3: Flowchart to Obtain the Economic Loss of Enterprises Where the Consumption Area is in the Disaster Area**




Source: Fukushima, Hayashi, and Yashiro (2009).

### (3) Economic Loss Where Both the Production and Consumption Areas Are in the Disaster Area

Where both the production and consumption areas are in the disaster area, the economic loss is estimated as the maximum of the losses in the previous two cases.

## 2.3 Sample Application

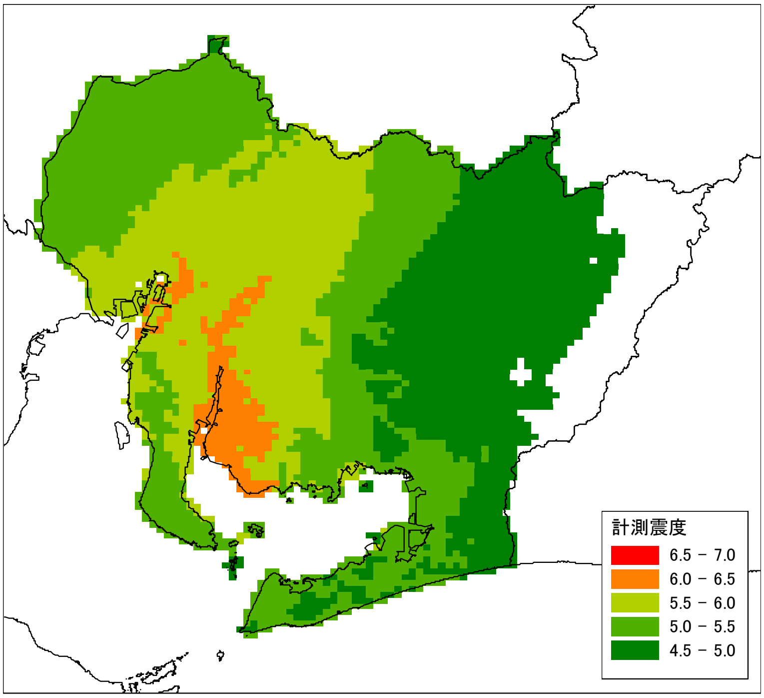
This section proposes methodology to evaluate economic loss at the regional level as well as for enterprises, based on the procedure by the Central Disaster Prevention Council in Japan. It applies the methodology to Aichi Prefecture, where Toyota and other major manufacturers are located, to illustrate how the evaluation is carried out.

### 2.3.1 Condition Setting

**(1) Earthquake and Seismic Hazard Scenario**

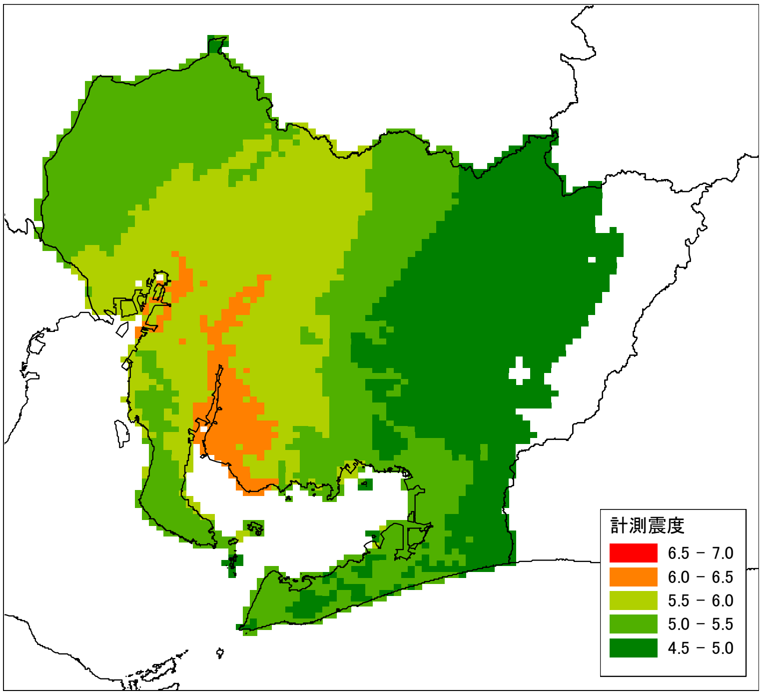
An earthquake occurring at Sanage fault is selected as the external event which yields economic loss to the region. The distribution of ground motion intensity and peak ground velocity are shown in Figures 2.4 and 2.5, respectively.

**Figure 2.4: Distribution of Ground Motion Intensity**




Source: Hayashi, Fukushima, and Yashiro (2009).

**Figure 2.5:** Distribution of Peak Ground Velocity



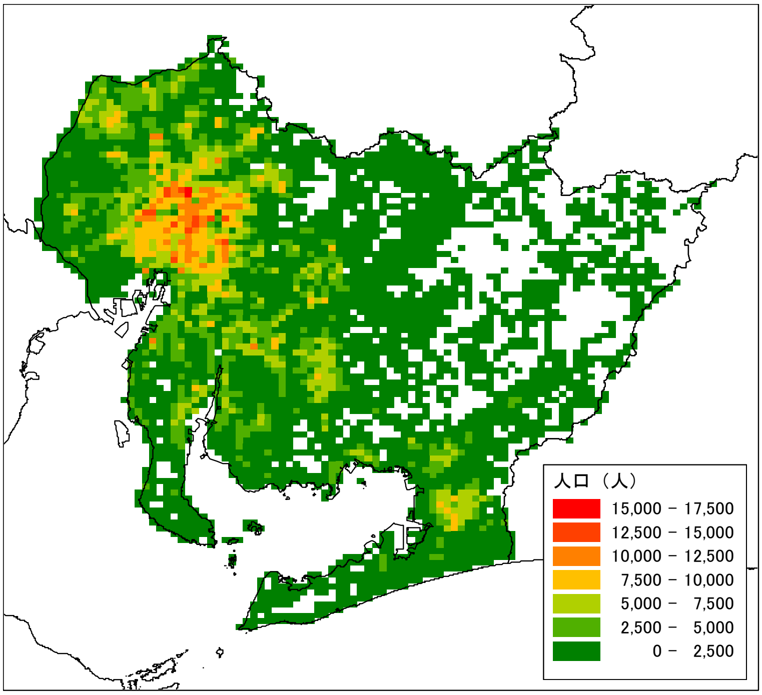

cm = centimetre, PGV = peak ground velocity, sec = second.

Source: Hayashi, Fukushima, and Yashiro (2009).

### (2) Distribution of Population and Buildings

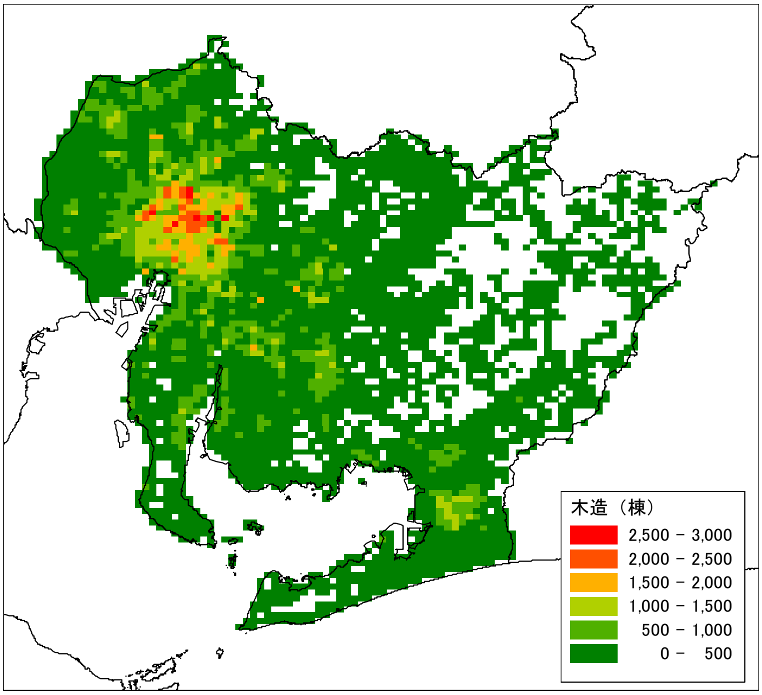
The distribution of population shown in Figure 2.6 is derived from Statistics Bureau (2005) prepared by Statistics Bureau in the Ministry of Internal Affairs and Communications. The distribution of buildings shown in Figure 2.7 is based on Statistics Bureau (2008). Table 2.3 shows the parameters for buildings' vulnerability based on past disasters.

**Figure 2.6:** Distribution of Population



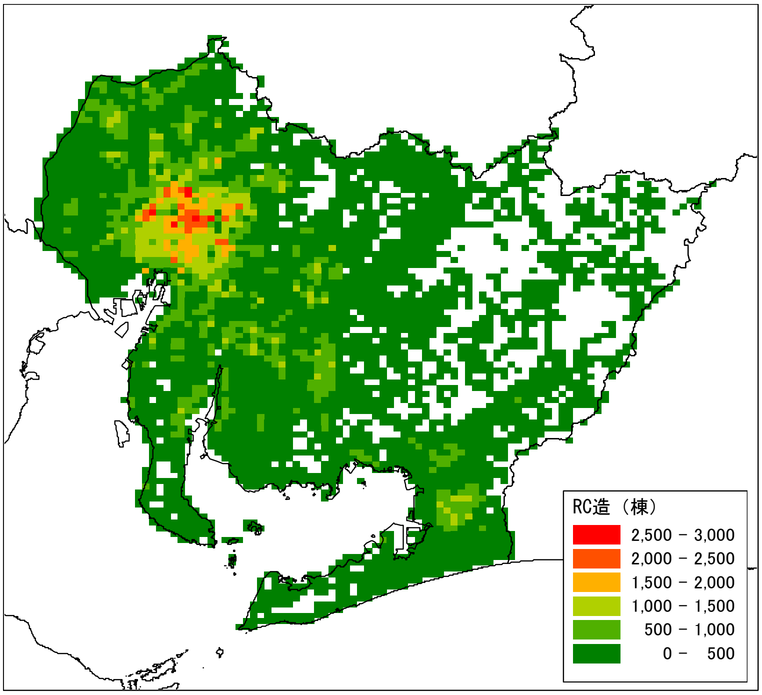

Source: Hayashi, Fukushima, and Yashiro (2009).

**Figure 2.7 (a):** Distribution of Wooden Buildings



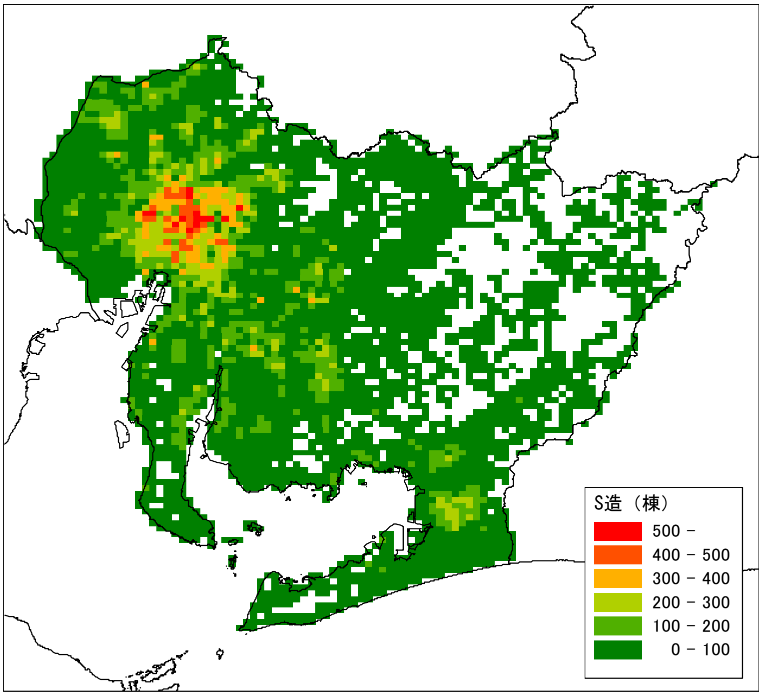

Source: Hayashi, Fukushima, and Yashiro (2009).

**Figure 2.7 (b): Distribution of Reinforced Concrete Buildings**




Source: Hayashi, Fukushima, and Yashiro (2009).

**Figure 2.7 (c): Distribution of Steel Buildings**




Source: Hayashi, Fukushima, and Yashiro (2009).

**Table 2.3:** Parameters of Buildings' Vulnerability

| Type of building | Collapsed | | Partially collapsed | |
|---|---|---|---|---|
| | Median (cm/s) | Log – normal standard deviation | Median (cm/s) | Log – normal standard deviation |
| Wooden/Residential (–1951) | 78.3 | 0.411 | 38.9 | 0.674 |
| Wooden/Residential (1952–1961) | 84.8 | 0.353 | 53.0 | 0.490 |
| Wooden/Residential (1962–1971) | 85.6 | 0.342 | 55.7 | 0.456 |
| Wooden/Residential (1972–1981) | 113.3 | 0.378 | 70.1 | 0.395 |
| Wooden/Residential (1981–) | 167.3 | 0.496 | 100.5 | 0.474 |
| RC/Non-residential (–1971) | 167.3 | 0.646 | 112.2 | 0.691 |
| RC/Non-residential (1972–1981) | 206.4 | 0.575 | 127.7 | 0.612 |
| RC/Non-residential (1982–) | 403.4 | 0.789 | 206.4 | 0.789 |
| Steel/Non-residential (–1971) | 103.5 | 0.819 | 70.1 | 0.712 |
| Steel/Non-residential (1972–1981) | 144.0 | 0.490 | 89.1 | 0.549 |
| Steel/Non-residential (1982–) | 281.5 | 0.731 | 149.9 | 0.733 |

cm = centimetre, RC = reinforced concrete, s = second.

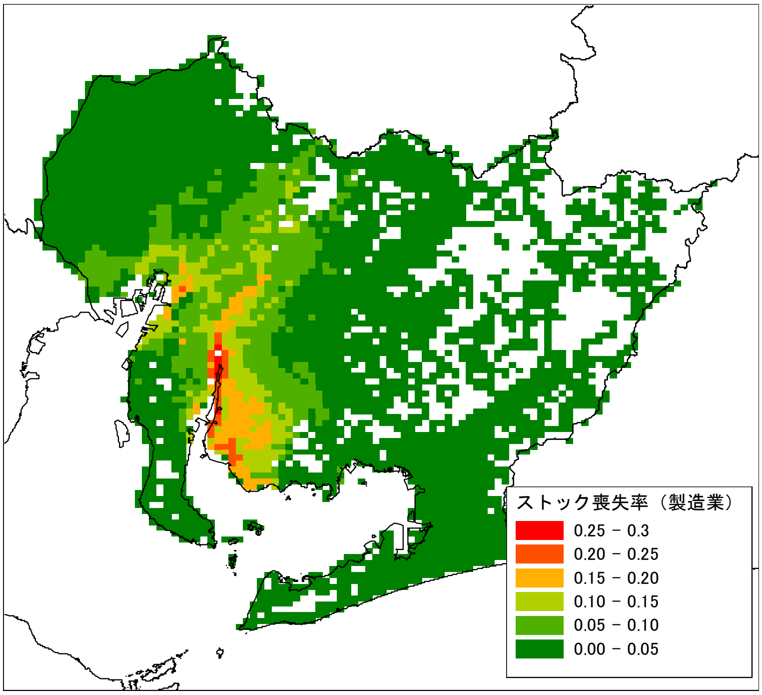
Source: Murao and Yamazaki (2000).

## 3.2 Result of Estimation

### (1) Reduction in Regional Productive Stock

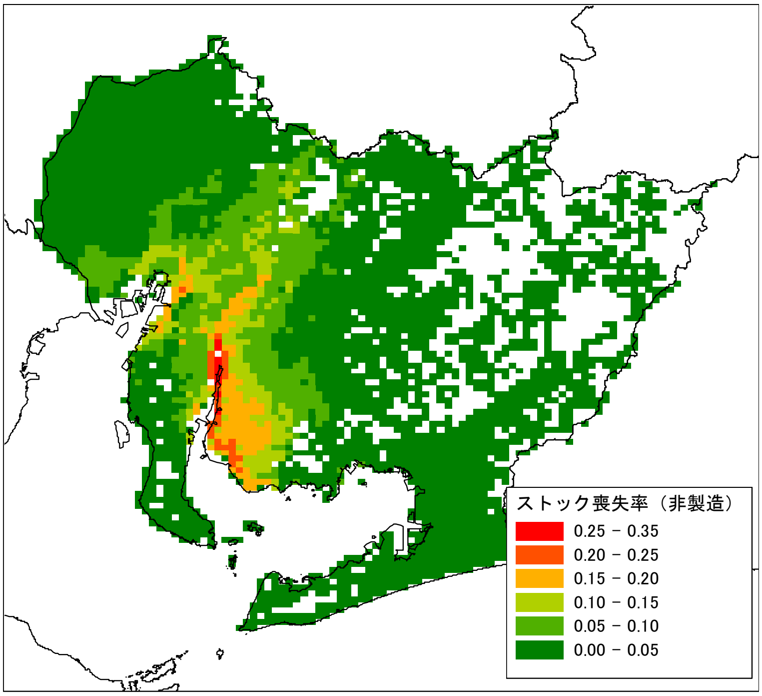
The distribution of the loss rate of capital stock and labour input is shown in Figures 2.8 and 2.9, respectively. The loss rate in each mesh is summed up and the total loss rates obtained are in Table 2.4.

**Figure 2.8 (a):** Distribution of Loss Rate of Capital Stock (Manufacturing Industry)



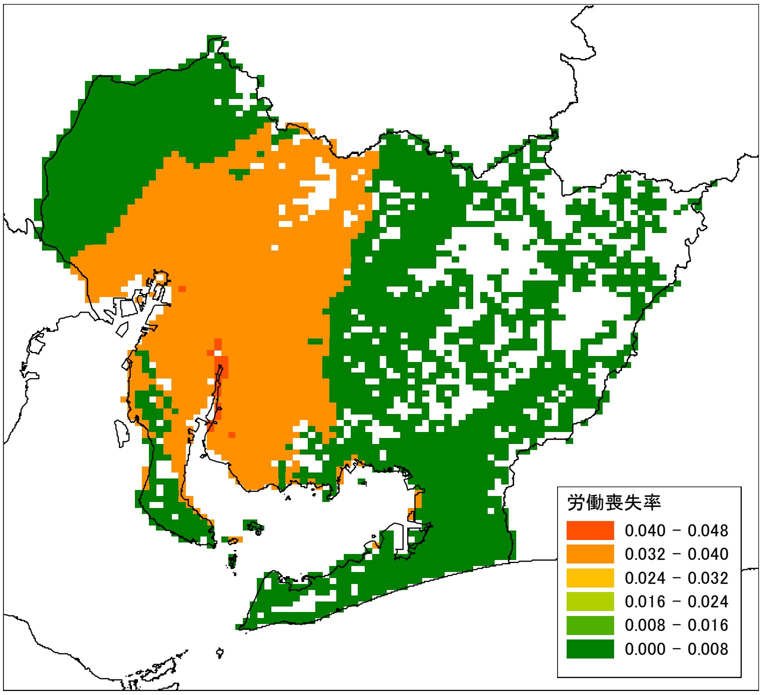

Source: Hayashi, Fukushima, and Yashiro (2009).

**Figure 2.8 (b):** Distribution of Loss Rate of Capital Stock (Non-manufacturing Sector)




Source: Hayashi, Fukushima, and Yashiro (2009).

**Figure 2.9:** Distribution of Loss Rate of Labour Input




Source: Hayashi, Fukushima, and Yashiro (2009).

**Table 2.4:** Total Loss Rates in Aichi Prefecture

| Capital stock (Manufacturing industry) | Capital stock (Non-manufacturing sector) | Labour input |
|---|---|---|
| 0.03443 | 0.03570 | 0.01533 |

Source: Hayashi, Fukushima, and Yashiro (2009).

### (2) Reduction in Production Value of Each Industry

The reduction in production value is estimated for 13 industries categorised in the I–O table for Aichi Prefecture. Table 2.5 summarises factors for the Cobb–Douglas production function and the results of estimation. The reduction rate for production value in the table is equal to the ratio of the final reduction in demand to GDP.

**Table 2.5:** Total Loss Rates in Aichi Prefecture

| Industry | Factors α for Cobb-Douglas production function | Reduction rate for production value (final reduction in demand) |
|---|---|---|
| Agriculture, forestry, and fisheries | 0.378 | 0.337 |
| Mining industry | 0.369 | 0.343 |
| Manufacturing industry | 0.384 | 0.330 |
| Construction industry | 0.326 | 0.377 |
| Electricity, gas, and water industry | 0.364 | 0.347 |
| Commerce | 0.353 | 0.355 |
| Finance and insurance | 0.563 | 0.290 |
| Real estate | 0.695 | 0.351 |
| Transportation | 0.495 | 0.290 |
| Communication and broadcasting | 0.495 | 0.290 |
| Official business | 0.448 | 0.302 |
| Service industry | 0.448 | 0.302 |
| Others | 0.448 | 0.302 |

Source: Hayashi, Fukushima, and Yashiro (2009).

### (3) Reduction in Output (1st and 2nd Ripple Effects)

Table 2.6 summarises the 1st and 2nd ripple effects for 13 industries. It shows a large difference in ripple effects amongst industries, though the difference in the reduction rate of industries is small, as shown in Table 2.5. For example, economic loss in the mining industry is several times of one by its own loss of production resources, and the ripple effect in real estate or official business is small.

**Table 2.6:** Ratio of Regional Economic Loss for GDP

| Industry | 1st Ripple effect | 2nd Ripple effect |
|---|---|---|
| Agriculture, forestry, and fisheries | 1.369 | 0.354 |
| Mining industry | 15.410 | 5.694 |
| Manufacturing industry | 0.816 | 0.202 |
| Construction industry | 0.440 | 0.106 |
| Electricity, gas, and water industry | 0.840 | 0.232 |
| Commerce | 0.625 | 0.240 |
| Finance and insurance | 0.880 | 0.325 |
| Real estate | 0.433 | 0.041 |

**Table 2.6:** Ratio of Regional Economic Loss for GDP (cont.)

| Industry | 1st Ripple effect | 2nd Ripple effect |
|---|---|---|
| Transportation | 0.823 | 0.310 |
| Communication and broadcasting | 0.678 | 0.221 |
| Official business | 0.302 | 0.082 |
| Service industry | 0.646 | 0.253 |
| Others | 2.709 | 1.329 |

GDP = gross domestic product.

Source: Hayashi, Fukushima, and Yashiro (2009).

## 2.4 Conclusion

In surveying the intrinsic complexity of disaster-prone ASEAN countries, this paper introduces various models, especially focusing on the I–O model, to examine economic losses and damages in the region considering the applicability and adaptability of the model and data availability. The I–O model can show the ripple effects from a disaster-affected area to a country and then to other countries and the region.

As a single disaster occurring in one country could directly and indirectly affect neighbouring countries and then a whole region, region-wide efforts for assessing the economic effects at the local, national, and regional level are required so that disaster risk reduction measures may be implemented accordingly.

This study has not yet applied the model to actual analyses because of the paucity and limited availability of both disaster and economic data for the ASEAN countries. The development of such data is indispensable for disaster loss analysis and highly required for the ASEAN region.

Nonetheless, the above-mentioned models can be applied not only to earthquakes but to other natural disasters by estimating the loss rates of capital stock and labour input, considering disaster- and country-specific characteristics.

## References

ASEAN (2016), *ASEAN Disaster Recovery Reference Guide*. Jakarta: ASEAN Secretariat.

Asian Disaster Reduction Center (2016), *Natural Disaster Data Book 2015: An Analytical Overview*. Kobe: Asian Disaster Reduction Center. http://www.adrc.asia/publications/databook/DB2015_e.html (accessed 1 December 2017).

Central Disaster Prevention Council of Japan (2008), 'Damage Estimation Methodology of Chubu and Kinki Regions Inland Earthquake'. Tokyo: Central Disaster Prevention Council of Japan. http://www.bousai.go.jp/kaigirep/chuobou/senmon/tounankai_nankaijishin/index_chukin.html (accessed 1 December 2017).

Fukushima, S., T. Hayashi, and H. Yashiro (2009), 'Study on Evaluation of Indirect Loss of Enterprise—Part 1: Methodology'. Transaction of Annual meeting of Architectural Institute of Japan, B-1, pp. 221–22

Hayashi T., S. Fukushima, and H. Yashiro (2009), 'Study on Evaluation of Indirect Loss of Enterprise—Part 2: Application'. Transaction of Annual meeting of Architectural Institute of Japan, B-1, pp. 223–24

Kajitani, Y., N. Yamano, and Y. Tatano (2005), 'Economic Impacts Caused by the 2004 Mid-Niigata Earthquake and Future *Tasks'2004-Nen nīgatanaka jishin ni yoru ji keizai e no eikyō to kongo no kadai* , *Infrastructure Planning Review*, 31.http://library.jsce.or.jp/jsce/open/00039/200506_no31/pdf/182.pdf (accessed 11 July 2017)

Kelly, S. (2015), 'Estimating Economic Loss from Cascading Infrastructure Failure: A Perspective on Modelling Interdependency', *Infrastructure Complexity*, 2(7), pp.1–13.

Ministry of Land, Infrastructure, Transport and Tourism (2013), 'Guideline for Flood Damage Indicator Analysis (2013 Trial Version)', *Suigai no higai shihyō bunseki no tebiki*. Tokyo: Ministry of Land, Infrastructure, Transport and Tourism. https://www.mlit.go.jp/river/basic_info/seisaku_hyouka/gaiyou/hyouka/pdf/higaisihyou_h25.pdf (accessed 1 December 2017).

Murao, O, and F. Yamazaki (2000), 'Development of Fragility Curves for Building based on Damage Survey Data of a Local Government after the 1995 Hyougo-ken-Nanbu Earthquake', *Journal of Struct. Constr. Eng., AIJ*, No.,527, Architectural Institute of Japan, pp.189–96.

Okuyama, Y. (2009), 'Critical Review of Methodologies on Disaster Impact Estimation', Background Paper for Assessment on the Economics of Disaster Risk Reduction. Washington, DC: Global Facility for Disaster Reduction and Recovery (GFDRR) and World Bank. https://www.gfdrr.org/sites/gfdrr/files/Okuyama_Critical_Review.pdf (accessed 1 December 2017)

Sawada, Y. and S. Oum (2012), 'Economic and Welfare Impacts of Disasters in East Asia and Policy Responses', in Y. Sawada and S. Oum (eds.) *Economic and Welfare Impacts of Disasters in East Asia and Policy Responses*, ERIA Research Project Report 2011-8. Jakarta: Economic Research Institute for ASEAN and East Asia (ERIA), pp.1–25.

Statistics Bureau (2005), *'POPULATION OF JAPAN (Final Report of the 2005 Population Census)'*, Statistics Bureau in the Ministry of Internal Affairs and Communications. http://www.stat.go.jp/english/data/kokusei/2005/nihon/index.html

Statistics Bureau (2008), *'Housing and Land Survey'*, Statistics Bureau in the Ministry of Internal Affairs and Communications. http://www.stat.go.jp/english/data/jyutaku/index.html

UNESCAP (2016), *Disasters in Asia and the Pacific: 2015 Year in Review*. Bangkok: UNESCAP. http://www.unescap.org/resources/disasters-asia-and-pacific-2015-year-review (accessed 1 December 2017).

Van der Veen, A. and C. Logtmeijer (2005), 'Economic Hotspots: Visualizing Vulnerability to Flooding', *Natural Hazards*, 36(1–2), pp.65–80.

World Bank, ASEAN, United Nations Office for Disaster Risk Reduction (UNISDR), and GFDRR (2010), *Synthesis Report on Ten ASEAN Countries Disaster Risks Assessment*, ASEAN Disaster Risk Management Initiative. Geneva: UNISDR. https://www.unisdr.org/we/inform/publications/18872 (accessed 1 December 2017).