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ORIGINAL ARTICLE

Approach of Estimating Tsunami Economic Losses in The Okinawa Island with Scenario-based of Input-Output Table and Okinawa Earthquake Sources

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***Abstract*:** Tsunamis are one of all the water related disasters in the earth, hugely affect to human life and economic losses. Understanding the value of tsunami damage that is important point for mitigation management. This study is pointed to present losses of tsunami damage in case study of the Okinawa Island, using tsunami hazard map and economic model. The tsunami hazard map is based on the earthquake scenario around the study area and computed from mathematic model (TUNAMI-N2). For tsunami simulation, the scenario cases have 16 cases that is represented by the earthquake event in the historical along the Ryukyu Trench and the Okinawa Trough. TUNAMI-N2 is developed by using the shallow water wave equation in 2D modeling. The hazard map resulted from the TUNAMI-N2 is overlaid with land cover map to identify the land cover hazard map for analysis in economic model. The Economic model of study area is presented by the Input-Output (I-O) table that industry sectors are scaled to relate with the land cover type. The relationships between the land cover hazard map and the land cover economic model is used to estimate the disaster losses in the directly and indirectly. The direct losses can be directly estimated from the total income of I-O table while the indirect loses is computed from unit cost of direct losses and interaction parameter of I-O table. The interaction parameter is formed in the linear programming and calculated by using the Leontief methodology. This approach has been discussed that the differences of tsunami potential damages and can be applied to sustainable management, providing the adaptation policy implementation.

Keywords: Tsunami hazard, Tsunami modeling, Tsunami damage losses, Economic losses

1. Introduction

Tsunami are one of all the major natural disasters, affecting in fatalities. An inundation caused by tsunami flooding have often affected an agriculture area, industry area and urban area. One's major factor on a damage of industry production is caused by floodwater. The effects of tsunami floods are expected to increase in the coming years because of population growth, population migration to coastal areas, and climate change (Feyen et al., 2006).

In case of Japan, agriculture, industry and urban

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which is a major production to export in the world has gotten damage from tsunami flooding occurred in 2011. The 2011 flood affected to urbanize sector with 300 kilometers along the Japan coast and total damage amounted to USD 30,000 million of area in the whole country. Therefore, developing a mitigation of tsunami is important strategies that can be done by using the accuracy data in historical of disaster damage assessment.

In tsunami mitigation and adaptation, damage cost estimation is important for decision making to do it. The tsunami flood damage does not only estimate the direct loss that also brings several indirect economic losses. The indirect losses have combined with many economics sectors that are interlinked and the spatial divisions. The indirect damage costs are derived from the direct loss and estimated by using inter-regional input-output table to consider the transactions among regions country and economic sectors.

Inter-regional input-output (IRIO) table is needed to explain the production, conducting in each products and each region. IRIO table covers multiple regions at the same time, describing transaction relationships of goods. The IRIO table reveals not only in international markets but also in domestic trades between regions. For goods and services produced in each region answered in how much was consumed by which region's which industry or final demand are presented in this table (METI, 2010). Input-output table and damage cost analysis is a powerful valuation tool that combines economic values and disaster area in each industrial sector so as to value loss, defined as trading the indirect loss that was affected to other product (Hasegawa et al., 2009).

However, there is little demonstrate in the application of IRIO table for evaluating tsunami economic loss in each economic product such as agriculture, industry and urbanization, for a number of reasons. The IRIO table represented of an economic approach of the region that is necessary to understanding for utilization. The data for cost value in each industrial sector is not accessible.

The objective of this study is to identify the tsunami inundation map with TUNAMI-N2 model and earthquake sources scenario, and estimate tsunami flood damage cost on direct and indirect loss based on economic structure represented by using IRIO table. The case study was selected by using the Okinawa Island in Japan (see **Figure 1**).

2. Methodology

This paper has done by 2 model components, tsunami simulation model and economic losses model. The linkage of model is shown in **Figure 2** to estimate the tsunami economic losses on direct losses and indirect losses.

2.1 Numerical tsunami simulation

To get the tsunami hazard map for the study area, a numerical tsunami model was driven by using the TUNAMI-N2 model (Imamura, 1995) with grid system of 2,430 m, 810 m, 270 m, and 90 m, as presented in **Figure 3**. The tsunami hazard map was interpreted by a 90 m resolution along the coast line of study area.

The TUNAMI-N2 model was initially established by Tohoku University to model tsunami propagation and inundation represented by a leap-frog mathematic scheme on a non-linear of shallow water equation. To model tsunami propagation and inundation, initial water level deformation was computed by using a rectangular fault model (Okada, 1985) and fault parameter of Okinawa earthquake scenario was based on 16 faults model, as presented in **Figure 4**.

2.2 Direct economic losses

The generated process of this step is as follow. First, Land cover dataset are provided by Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan consisted with 13 categories that area was concluded on in square kilometer. The area of land cover was added as a new row of an aggregated IRIO table. In this step, unit cost of land cover type was used to calculate output per unit area (1,000 million US / square kilometer) of production cost, value added, and total production. Finally, the inundation area in previous process combined using data of output per area was used to estimate the flood damage cost as the direct economic losses.

Reliability and accuracy of IRIO table are the important topics. This is the reason why we use only secondary data published by Japanese government agencies such as IDE-JETRO. All data used in this paper is collected by a survey method by IDE-JETRO.

2.3 Input-output method for indirect economic losses

The input-output analysis can estimate indirect economic effects with economic linkage among sector or regions into account. Ordinal demand side I-O model was presented by W. Leontief after the Second World War (Suttinon and Nasu 2010). An input-output table is explained in a monetary matrix (row and column) format containing inter-industry transactions. The rows of the matrix describe the distribution of output (product sale structure). The columns display input (purchase structure), the sum of raw materials and value added expenses. However, a traditional I-O table is only demonstrated in one region. This reveals that an effect of domestic trade cannot be presented.

In addition to flooding, it would have significant influence on certain fields as an agricultural productivity and capacity of firms. Direct effect on flooding is determined as the change on outputs in specific sectors. Hence, it is appropriate to concern the outputs in the particular sectors damaged directly as exogenous variables when estimating indirect effect of disasters as flooding. Here, I-O model with mixed variables was applied to estimate the economic impact of flooding (Hasegawa et al. 2009).

The model included by mixed variables is descripted as follow. First, vector of output is formulated from the sum of intermediate transaction and final demand into equation (1). Then, the equation (1) was changed into the matrix format as equation (2) that is illustrated with the basic equation for I-O analysis with Leontief inverse matrix.

$$x = A \cdot x + f \tag{1}$$

$$x = (I - A)^{-1} \cdot f = L \cdot f \tag{2}$$

where $\boldsymbol{x}$ = vector of output, $\boldsymbol{f}$ = vector of final demand, $\boldsymbol{A}$ = matrix of input coefficient, $\boldsymbol{I}$ = identity matrix, $\boldsymbol{L}$ = Leontief inverse matrix $(\boldsymbol{I}\text{-}\boldsymbol{A})^{-1}$as $[\boldsymbol{l_{ij}}]$.

When three sectors are assumed for the I-O table, the equation (3) can be shown as follows.

$$\begin{bmatrix} x_1 \\ x_2 \\ x_2 \end{bmatrix} = \begin{bmatrix} L_{11} & L_{12} & L_{13} \\ L_{21} & L_{22} & L_{23} \\ L_{31} & L_{32} & L_{33} \end{bmatrix} \cdot \begin{bmatrix} f_1 \\ f_2 \\ f_3 \end{bmatrix} \tag{3}$$

For indirect losses estimation, given that $\boldsymbol{d_1}$ as direct losses at sector 1st on $\boldsymbol{f_1}$ while $\boldsymbol{f_2}$ and $\boldsymbol{f_3}$ are 0. In Leontief inverse matrix, the coefficient of sector 1st is also changed for estimating the indirect losses of this sector as $\boldsymbol{\Delta x_{d1}}$. The other indirect losses, $\boldsymbol{x_2}$ and $\boldsymbol{x_3}$, affected by $\boldsymbol{d_1}$ are investigated by equation as follow:

$$\begin{bmatrix} \Delta x_1 \\ x_2 \\ x_2 \end{bmatrix} = \begin{bmatrix} (L_{11}-1) & L_{12} & L_{13} \\ L_{21} & L_{22} & L_{23} \\ L_{31} & L_{32} & L_{33} \end{bmatrix} \cdot \begin{bmatrix} d_1 \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

This paper applied the model based on the equation (4) to the IRIO table in order to indirect economic loss of tsunami flood disaster on the industry sector production. This IRIO table is limited for some specific country (Indonesia, Malaysia, Philippines, Singapore, Thailand, China, Taiwan, Korea, Japan, and USA) based on economic structure in 2005.

3. Results and Discussion

3.1 Tsunami flood hazard map

Figure 5 shows the inundation area that its damage area from TUNAMI model, based on the 16 scenario faults. The damaged areas over the 16 faults were 91.862 square kilometers. The inundation in ranging from 2.0 – 5.0 m is the largest area about 37.34 square kilometers, and followed by 1.0 – 2.0 m and > 5.0 m. When the inundation results were overlaid with land cover map at the same location by using GIS technique, **Table 1** displays the estimated spatial inundation area in each land cover type. The inundation damage in Urban area occurred over area about 31.93 square kilometers that is the largest among land cover type. The second largest damage occurred in Bar land, and the least damage was in Paddy.

3.2 Tsunami damage cost estimation

Inter-regional input-output table and flood losses on rice product of Thailand region are calculated from traditional inter-regional table and remote sensing technique. **Table 2** displays the inter-regional input-output (IRIO) table of Thailand with two sectors and the other country with summary in 2005. There are three different parts: (1) aggregated inter-regional input-output (IRIO) table in a monetary unit; (2) land cover area unit cost estimation in unit of million US / square kilometers; and (3) direct losses calculation in unit of million US.

As can be seen in IRIO part of **Table 2**, the status of regional economics of Thailand and the other country in 2005 is summarized. All input and output values in each I-O table are related for a number of sectors; for example, intermediate demand, value added, final demand, trade, and total outputs.

As can be seen in part of land cover area unit price of **Table 2**, total area of Japan is about 378,000 square kilometers. The total area was used to calculate the area unit cost by using the total output in the IRIO table. In this study based on the IRIO table, the area unit cost is about 22.79 million US / square kilometers for Japan.

As can be seen in part of direct damage cost estimation of **Table 2**, total flood area resulting from the previous process is about 91.86 square kilometers on 2005 to relate with the IRIO table used. The tsunami damage area was used to estimate the direct losses by using the area unit cost from a previous part of the IRIO table. For rice production of Thailand based on flood disaster in 2005, the direct losses are about 2,094 million US.

Next, indirect economic losses are considered by the proposed algorithm. **Table 3** displays the total economic losses that consist of direct and indirect losses which the total indirect damage cost is 3,835.8 million US about 183.18% of the direct losses. On the indirect losses in Japan country region, the damage cost between flooding and non-flooding is 3,68.2 million US. To compare losses with other country, the most damage in China is about 44.8 million US with 2.14% of the direct losses. The second country largest damage is about 37.8 million US on 1.8% of the direct damage cost that is occurred in USA, and next, Korea is 16.5 million US about 0.79% of direct losses.

4. Conclusion

The aim in this study was to consider the degree of flood damage caused by the tsunami in Okinawa Island, Japan, based on 16 scenarios of earthquake. To estimate the spatial of tsunami flood damage, we used the TUNAMI model with grid systematic from 2,430 m, 810 m, 270 m, and 90 m. We achieve that the inundation area is at 90 m resolution. The damaged areas over 16 scenarios were 91.862 square kilometers. Our result shown that the tsunami flood area was largely occurred in Urban area with 2.0 – 5.0 m.

The Inter-regional input-output (IRIO) table can be used to quantify the direct and indirect losses or trade in economic losses of flood disaster in each region and each sector. The main advantage of the IRIO table is that it combines the traditional inter-regional input-output table and allows policy makers to clearly understand the path of flood disaster based on value of cost. The IRIO approach presented here is a descriptive device that is workable with various regions and industrial sectors (paddy and non-paddy). It is one of powerful tools for considering damage cost between regions.

Future research should focus on: (1) the higher resolution images, as optical sensors developed available in the near future; (2) global scale, with other industry sectors and make more region; (3) country scale, with divided into manufacture and service sectors.

Acknowledgments

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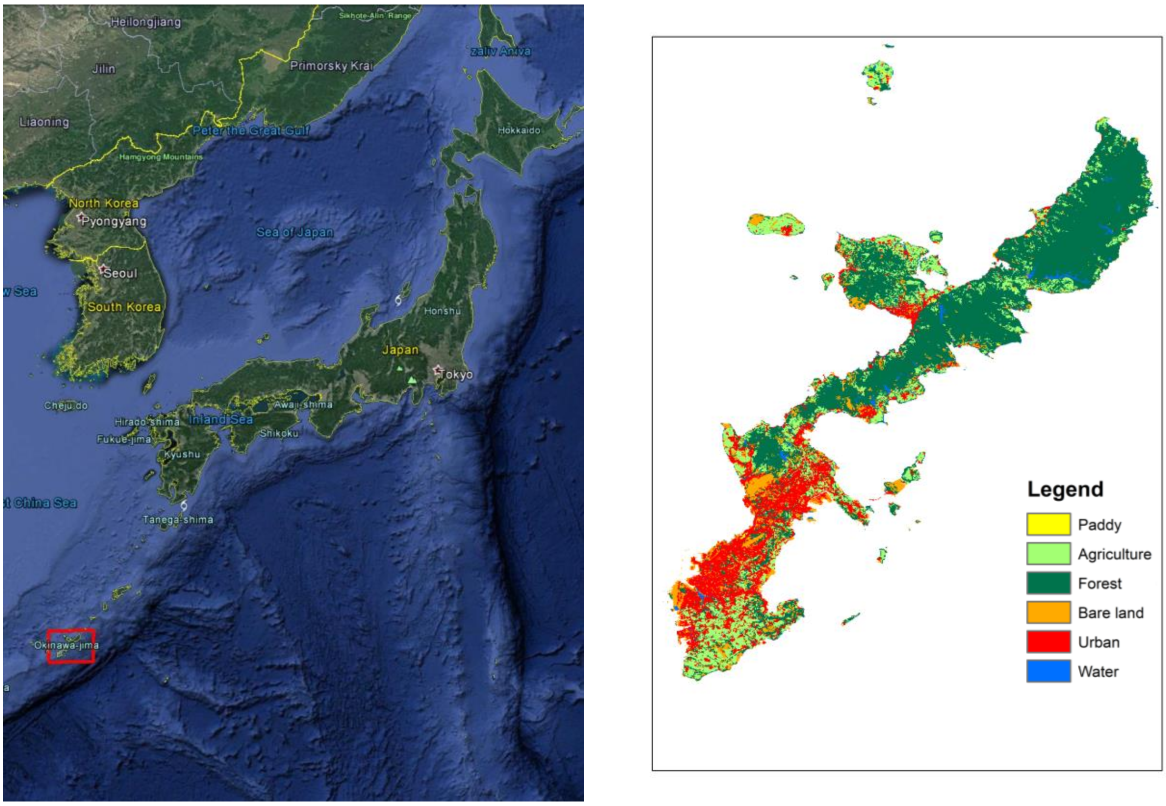


a) Location of Okinawa Island b) Land cover map of Okinawa Island

Figure 1 Okinawa Island, Location and land cover map

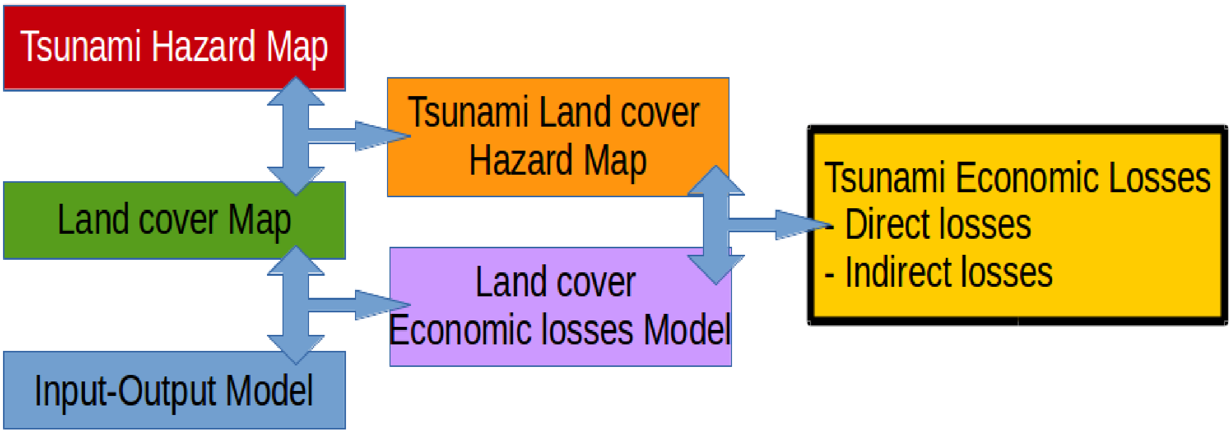


Figure 2 Main methodology for estimating the tsunami economic losses

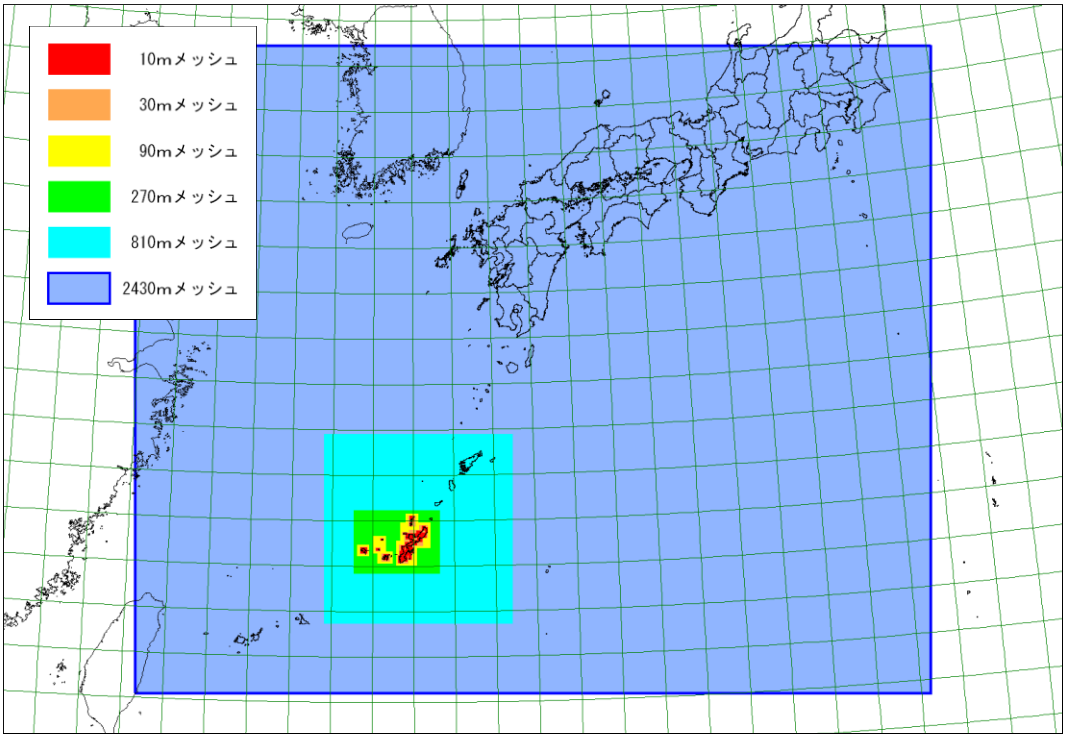
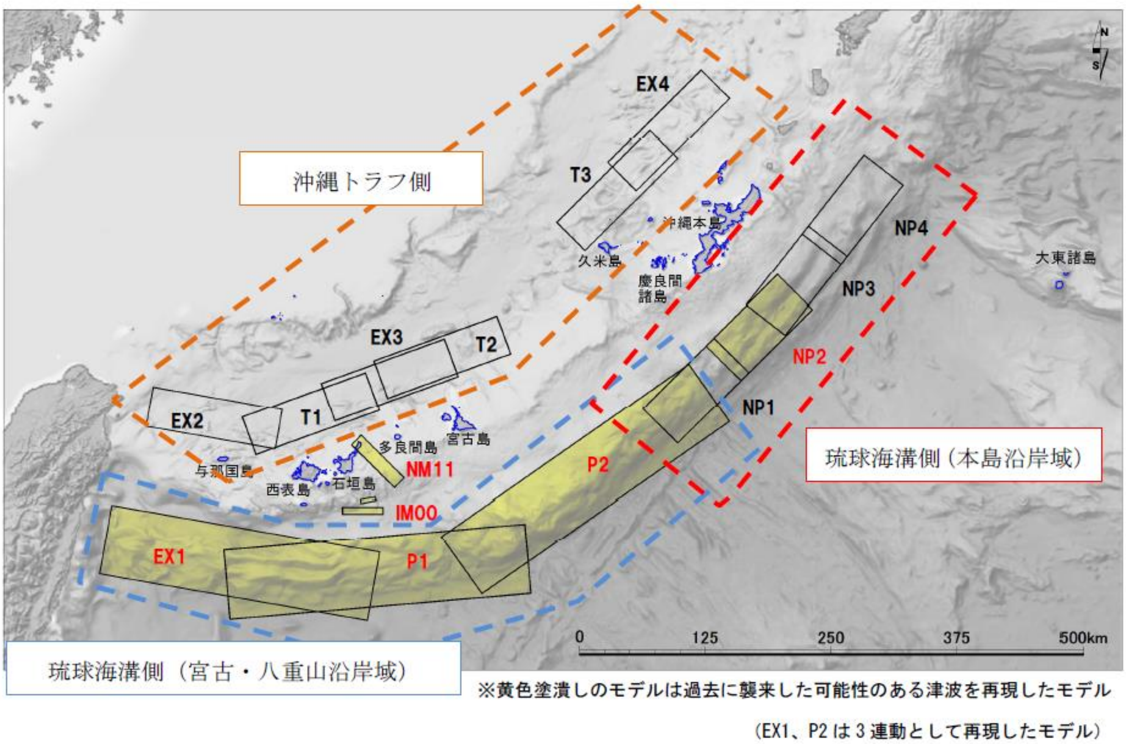


Figure 3 Systematic of grid to simulate tsunami for Okinawa Island



Source: Okinawa prefaceture tsunami report

Figure 4 Faults location around the Okinawa Island

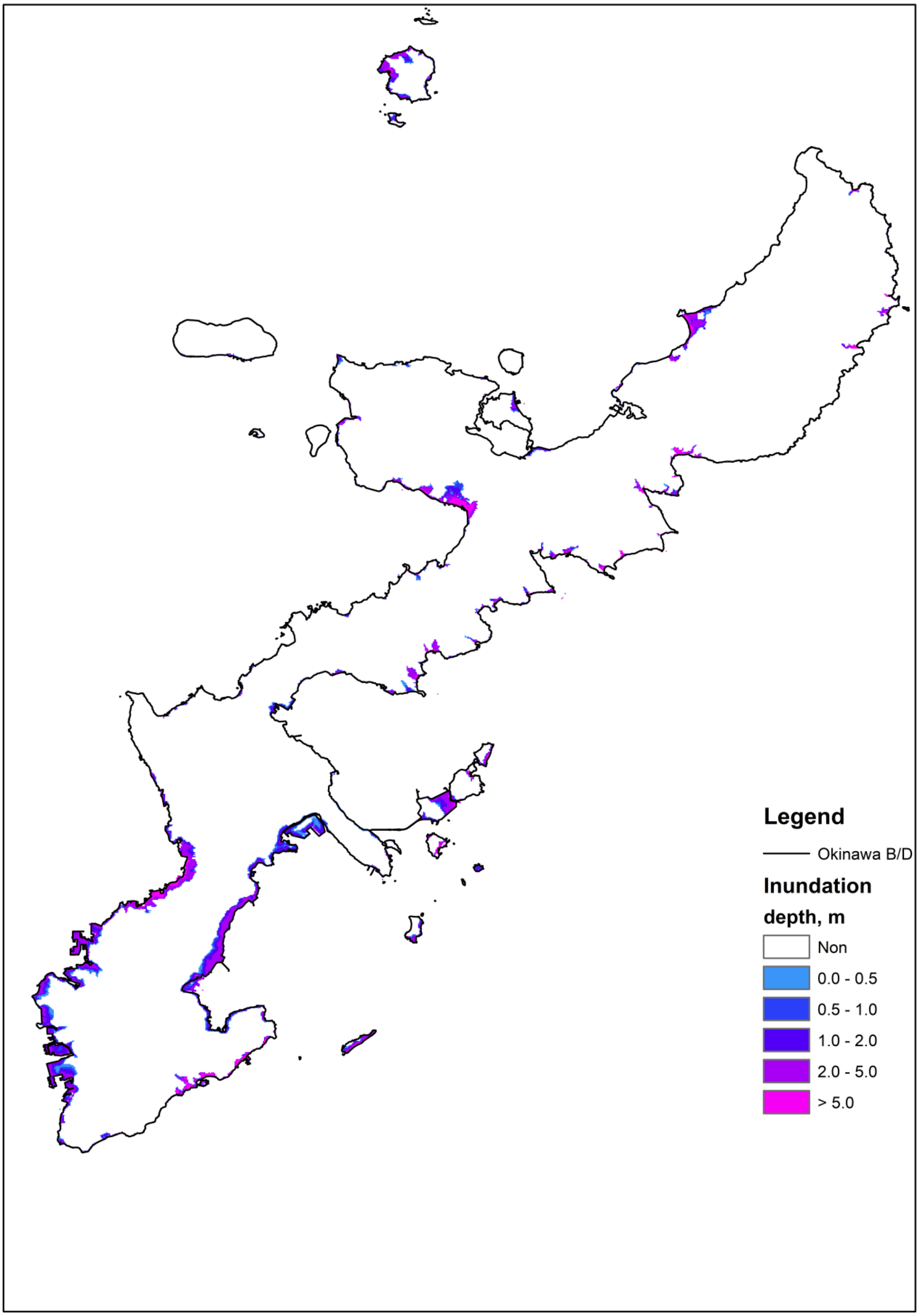

Legend
Okinawa B/D
Inundation
depth, m
Non
0.0 - 0.5
0.5 - 1.0
1.0 - 2.0
2.0 - 5.0
> 5.0

Figure 5 Inundation map, resulting from 16 faults around the Okinawa Island

Table 1 Inundation area in each land cover type

Land-cover	*Tsunami Inundation depth meter, sq.km*					
	0.0 - 0.5	0.5 - 1.0	1.0 - 2.0	2.0 - 5.0	> 5.0	Total
Paddy	0.073	0.049	0.243	0.462	0.122	0.948
Agriculture	2.187	1.879	3.353	6.197	2.114	15.730
Forest	1.296	0.851	1.531	3.167	2.001	8.845
Bar land	2.430	2.057	5.022	10.360	2.803	22.672
Urban	4.066	4.269	8.262	11.915	3.418	31.930
Water	0.713	0.729	1.717	5.241	3.337	11.737
Total	10.765	9.833	20.129	37.341	13.794	91.862

Table 3 Direct and indirect economic losses among industrial sectors and other region

Loss Types	Regions	Cost, 1,000 million US	% of direct
Direct	**Japan**	2.0940	100.00%
Indirect	**Japan**	3.6882	176.13%
	Thailand	0.0077	0.37%
	China	0.0448	2.14%
	Malaysia	0.0089	0.43%
	USA	0.0378	1.80%
	Indonesia	0.0131	0.63%
	Korea	0.0165	0.79%
	Taiwan	0.0104	0.50%
	Singapore	0.0054	0.26%
	Philippines	0.0029	0.14%
	Total	3.8358	183.18%

Table 2 Inter-regional input-output (IRIO) table of Okinawa in Japan and other country in summary on 2005

Part I: IRIO table (2005) Unit: 1,000 million US		Intermediate Demand(A)										Final Demand	Inter. trade		Total output
		Indonesia (AI)	Malaysia (AM)	Philippines (AP)	Singapore (AS)	**Thailand (paddy)** (ATP)	China (AC)	Taiwan (AN)	Korea (AK)	Japan (AJ)	USA (AU)	(F)	Exports (E)	Imports (I)	(XX)
Intermediate Transaction	Indonesia (AI)	231.27	2.79	0.87	6.61	0.03	6.94	3.64	7.68	17.70	3.69	267.60	65.63	-30.12	586.14
	Malaysia (AM)	2.18	194.22	1.51	6.31	0.06	15.67	3.83	4.80	10.19	16.12	108.53	89.57	-34.44	423.77
	Philippines (AP)	0.20	0.90	95.44	1.55	0.00	4.11	1.46	1.43	3.71	3.86	109.64	38.03	-21.75	239.74
	Singapore (AS)	4.40	9.15	2.75	90.45	0.00	12.99	3.57	7.94	7.61	8.41	72.82	156.42	-65.03	314.65
	Thailand (paddy) (ATP)	-	-	0.00014	-	0.18	-	0.00007	-	0.00002	-	0.477	0.3401	-0.8403	4.57
	China (AC)	5.83	10.03	2.35	7.08	0.06	3,853.32	13.44	23.71	41.64	72.44	2,140.833	809.93	-316.42	6,672.50
	Taiwan (AN)	1.07	5.02	2.34	4.67	0.00	33.61	295.17	6.67	14.02	17.11	322.918	172.43	-72.18	805.85
	Korea (AK)	2.35	3.69	1.67	1.98	0.01	52.24	10.06	891.57	19.48	20.46	803.680	309.55	-138.65	1,981.89
	Japan (AJ)	6.60	12.86	5.98	6.89	0.01	65.69	29.95	39.64	3,719.27	60.03	4,387.361	534.45	-268.99	8,616.02
	USA (AU)	2.83	9.26	3.15	16.57	0.03	29.32	14.52	25.78	47.89	9,838.29	12,362.596	1,851.99	-900.00	23,311.46
Value added	(VV)	326.56	170.78	122.56	169.80	3.43	2,589.41	428.05	970.56	4,724.35	13,260.74				
Total input	(XX)	586.14	423.77	239.74	314.65	4.57	6,672.50	805.85	1,981.89	8,616.02	23,311.46				
Part II: Land cover Area, $10^3 km^2$		-	-	-	-	-	-	-	-	378.00	-				
L/C unit price, Cost/U.Area		-	-	-	-	-	-	-	-	22.794	-				
Part III: Flood Area, $10^3 km^2$		-	-	-	-	-	-	-	-	0.09186	-				
Direct loss, 1,000 million US		-	-	-	-	-	-	-	-	2.094	-				