Tsunami Economic Losses of the Nankai Earthquake in Kochi Prefecture Estimated with Scenario Base of Input-Output Modeling

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1. Introduction: Tsunamis are one of all the water related disasters in the world, impact to human life and economic losses. Understanding the value of tsunami damage that is important point for the tsunami prevention. 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. This study aims to present losses of tsunami in case study of the Nankai Earthquake in the Kochi Prefecture, using tsunami hazard map and economic transaction model, based on the Inter-Regional Input Output (IRIO) model. The selected area was presented by **Fig. 1**.

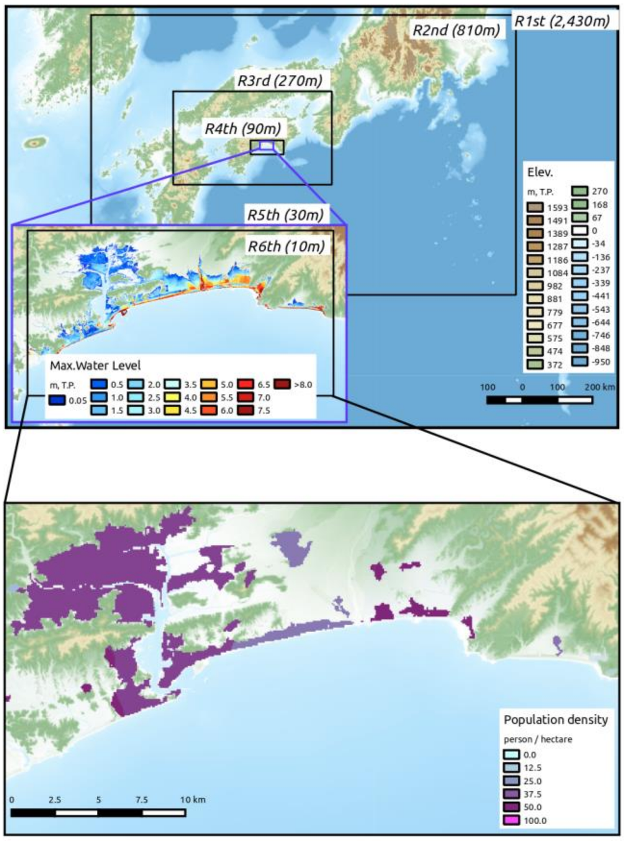

Fig. 1 Study area, Bathymetry data, Simulation results and Population density in the study area

2. Methodology: This paper has done by 2 components, tsunami simulation model and economic losses model. The study flow is shown in **Fig. 2** to consider the tsunami direct losses and indirect losses.

2.1 Tsunami numerical model: To estimate the tsunami hazard map for the selected area, a tsunami model was simulated by using the TUNAMI-N2 model (Imamura, 1995) with grid system of 2,430 m, 810 m, 270 m, 90 m, 30 m and 10 m as presented in **Fig. 1**. The tsunami hazard map was interpreted by a 10 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. For tsunami simulation, the scenario cases have 11 cases that is represented by the earthquake event in the historical along the Nankai Trough.

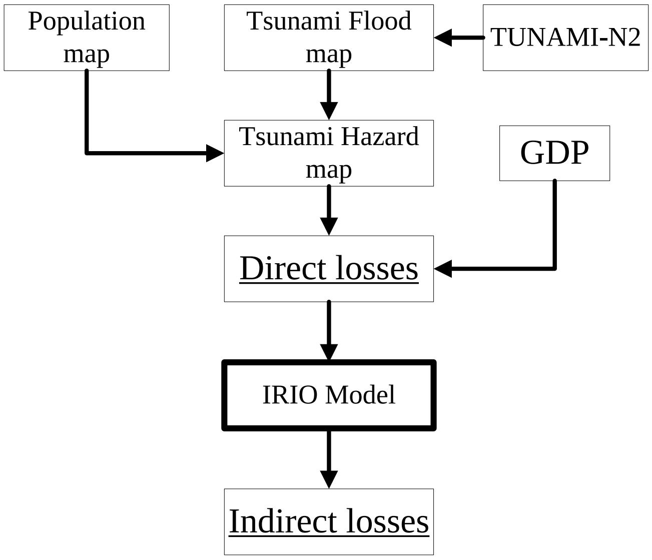

Fig. 2 Stream flow to estimate the tsunami economic losses

2.2 Economic direct losses: The generated process of this step is as follow. First, population density map is provided by the WorldPop project datasets, GeoData Institute, University of Southampton, England that area was concluded on number of people per hectare. The population density of the study area was shown in the **Fig.1** that have the average of 50 persons per hectare. Next, the population map overlay to the tsunami flood map that result become to tsunami hazard map, using to present the number of stakeholder. Third, the tsunami hazard map is multiplied by GDP to present a losses map. In the study, the GDP of Kochi City is about 2.3 million yens. The direct loses is the summation of the losses map.

2.3 Economic indirect losses: The input-output analysis can estimate indirect economic effects with economic linkage among sector or regions into account. Ordinal demand side of I-O model was presented by W. Leontief after the Second World War (Pakoksung 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. 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.

$$x = A \cdot x + f \qquad (1)$$

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

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 $(\boldsymbol{I}-\boldsymbol{A})^{-1}$as $[\boldsymbol{l_{ij}}]$. 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:

$$\begin{bmatrix} \Delta x_1 \\ x_2 \\ x_2 \end{bmatrix} = \begin{bmatrix} (L_{11}-1) & L_{12} & L_{13} \\ L_{21} & L_{22} & L_{23} \\ L_{31} & L_{32} & L_{33} \end{bmatrix} \cdot \begin{bmatrix} d_1 \\ 0 \\ 0 \end{bmatrix} \qquad (3)$$

3. Results and Discussion

3.1 Tsunami hazard amp

Fig. 1 shows the inundation area that the damage area estimated from TUNAMI model, based on 11 scenarios of Nankai earthquake. The damaged areas over the 11 scenarios were about 40 square kilometers. The inundation depth is in ranging from 0.5 – 8.0 m. When the inundation map results were overlaid with population map at the same location by using GIS technique, tsunami hazard map was estimated by showing the number of stakeholder. The stakeholder losses can be represented by GDP. **Fig. 3** shows the spatial of tsunami losses that is based on the multiplying between the GDP of the Kochi prefecture and the tsunami hazard map, as direct losses. The direct losses totally are about 2.3 billion yens.

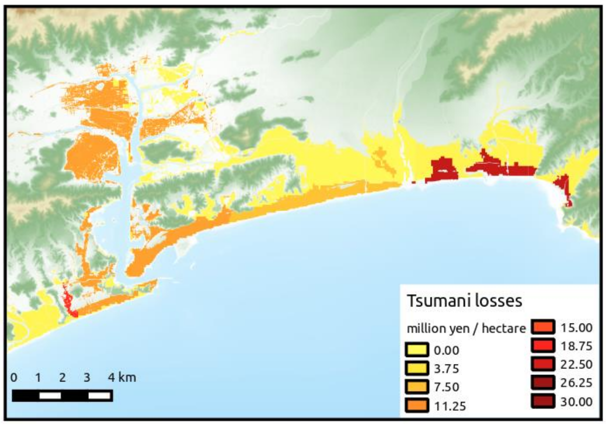

Fig. 3 Tsunami hazard map showed in economic direct losses

Next, indirect economic losses are considered by the proposed algorithm and direct losses. **Table 1** displays the total economic losses that consist of direct and indirect losses which the total indirect damage cost is 3.2 billion yen about 140% of the direct losses. On the indirect losses of Kochi in region of Shikoku region, the damage cost between flooding and non-flooding is 1.8 billion yen. To compare losses with other region, the most damage in Kanto is about 0.477 billion yen with 20% of the direct losses. The second country largest damage is about 0.32 billion yen on 14% of the direct damage cost that is occurred in Kinki, and next, Chugoku is 0.23 billion yen about 10% of direct losses. The smallest effect is the Hokkaido and Okinawa, is about 1%.

Table 1 Direct and indirect economic losses among industrial sectors and other region

Loss	Region	Cost, Billion yen	Ratio of direct loss
Direct	Shikoku	2.300	100%
Indirect	Shikoku	1.800	78%
	Hokkaido	0.034	1%
	Tohoku	0.058	2%
	Kanto	0.477	20%
	Chubu	0.193	8%
	Kinki	0.318	14%
	Chugoku	0.233	10%
	Kyusyu	0.122	5%
	Okinawa	0.020	1%
	Total	3.300	140%

4. Conclusion

The aim in this paper was to consider the degree of flood damage caused by the tsunami in Kochi prefecture, Shikoku Island, Japan, based on 11 scenarios of Nankai 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, 90 m, 30 m and 10 m. We achieve that the inundation area is at 10 m resolution. The damaged areas over 11 scenarios were 40 square kilometers. The IRIO table can be used to quantify the direct and indirect losses in economic losses. The main advantage of the IRIO table is that it combines the traditional and allows policy makers to clearly understand the path of disaster based on value of cost. It is one of powerful tools for considering disaster damage cost between regions and region.

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