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Evacuation, Post-disaster Reconstruction and Improvement Management from QOL Standards in Disasters

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***ABSTRACT*:** In case of severe disasters, the QOL (Quality of Life) of disaster victims is greatly lowered by the damage to residences and infrastructure which make living inconvenient. Yet, in the phases of evacuation, post-disaster reconstruction and improvement, there are few ideas as to how to identify the process to reconstruct new residences and infrastructure in the disaster area. And, discussions are also required on how to reinforce infrastructure networks in the pre-disaster prevention phase.

This study proposes the method of applying QOL standards for evacuation, post-disaster reconstruction and improvement management in the disaster area. Taking the physical conditions of the residential areas and subjective sense of the residents into consideration, a QOL indicator is designed. First, with regard to the physical conditions, Life Prospects (LPs) consist of Accessibility (AC), Amenity (AM) and Safety & Security (SS). The QOL indicator is quantified as a sum of the LPs weighted by the subjective sense of residents. It is also taken into consideration in weighting parameters that the needs of disaster victims undergo a dynamic transition through each post-disaster phase.

Based on this evaluation method, we evaluate the AC to hospitals in the Tohoku coastal area that suffered severe damage from an earthquake on March 11th 2011, and in the Tokai area which is expected to suffer similarly in the near future. Main findings are as follows: a) In the Tohoku case study, AC along the Sanriku shoreline was greatly decreased. On the other hand, in some inland areas the decrease of AC was suppressed. b) Meanwhile, from time series comparison, recovery of AC has also been observed. The recovery is remarkable in the central area of Sendai city which has a rich road network. c) The analysis on the Tokai area reveals that AC in coastal areas was greatly decreased because of collapse of road network and decrease in hospital functioning. On the other hand, decrement in AC was suppressed in some urban areas such as Nagoya where many hospitals and tight road networks exist.

KEYWORDS: QOL, land use, urban planning, risk management

1. INTRODUCTION

During “The Great East Japan Earthquake” on 11 March 2011, the earthquake and the triggered tsunami cut off transportation networks at many places and various types of secondary damage also occurred. Consequently, there were many isolated regions where relief supplies could not be delivered. Furthermore, because there were no guidelines to process information during emergencies, mismatches arose between needs and supply during the phase of relief goods transportation. It accordingly reveals the difficulty in constructing a support regime that can satisfy the needs of victims without any trouble. After that, it is observed that the Quality of Life (QOL) of disaster victims, such as accessibility of hospitals from the evacuation site or the residential area, had been low.

In the "Tokai-Sanrendou Earthquake" which is expected to occur in the near future, the Tokai region will be assumed to suffer heavy damage, similar to "The Great East Japan Earthquake. (Mie prefecture has a sawtooth coastline similar to the Sanriku region, while both Aichi and Shizuoka prefectures face the sea). There exists the need for a management method for protecting the residents' Quality of Life from disasters.

In this study, we develop a refugee's Quality of Life (QOL) evaluation system, whose determination mechanisms change dynamically through each phase of the post-disaster period. We can also discuss countermeasures to decrease QOL attrition in each phase, such as road network reinforcement in the pre-disaster prevention phase and order of priority of recovering links in the post disaster reconstruction phase.

2. POSITIONING

Disaster damage is generally evaluated with direct indexes such as economic impact, number of deaths, or broken buildings. The existing disaster simulation system outputs those indexes in the standard[1]. However, we should take it into consideration that disaster damage has a long-term impact on daily life through a variety of paths. In related previous studies, some simple indicator such as days of isolation and disaster vulnerability from food stockpiling by the village is evaluated[2)3)]. But, consideration of the residents' living needs and its dynamic changing process in evacuation, post-disaster reconstruction and improvement periods are not enough.

Also, policies on land use and infrastructure development must be changed to mitigate disaster damage in high-risk regions. In contrast to the disaster areas where villages and infrastructures have seen some collapse, other regions do not have much risk consciousness. Consequently, it is hard to plan and implement the policy to re-construct residential areas gradually to reduce disaster risk. This makes it indispensable to develop a system to evaluate the influence of disaster damage from the residents' perspective with an easy-to-image index.

On the other hand, there are some evaluations of the victims' residential environment that used real data from the "Hanshin Awaji Earthquake disaster" (1995) and the "Chuetsu earthquake" (2004). These researches are no more than qualitative analyses; the quantitative aspect is not sufficient.

Because of the above background, disaster prevention plans are constructed individually by each municipality. There are no common management methods based on any scientific perspective. And, no method has been established to prioritize tasks in the reconstruction and improvement phase.

Therefore, we develop a system to evaluate disaster damage quantitatively and time-sequentially from the viewpoint of the residential environment. Although we concentrate on the AC index which comprises the QOL indicator in this paper, our final target is to construct a comprehensive evaluation method for disaster vulnerability by the village and to aid planning in reconstruction and improve management.

3. METHODOLOGY

The framework of this study is shown in Figure 1. Main target of this study is policy evaluation for the "Tokai-Sanrendou Earthquake"; however, for comparison, we additionally evaluate the result of "The Great East Japan Earthquake (2011)" with available real data. From the result of these analyses, we verify the feasibility of developing an evaluation system.

To represent a stochastic event, we apply Monte Carlo Simulation with the number of trials set to 20.

3.1 Disaster damage simulation

In this study, evaluation must be carried out before occurrence of the event; we must simulate the direct impacts of disaster. We thereby use the result of an earthquake simulation tool that simulates seismic intensity by the 500 m grid[1].

Based on assumed seismic intensity, we set the breakage rate for housing and infrastructure as equation (1).

$$p_k = \frac{1}{1+\exp(\alpha + \beta x_i)} \qquad (1)$$

p_k: breakage probability of link k.

x: seismic intensity of mesh i where the link exists.

α and β: parameters.

The parameters α and β are estimated from the results of "The Great East Japan Earthquake (2011)". If the generated random variable is found to be bigger than the breakage probability, the link is assumed to be unavailable. On the other hand, if the generated random variable is found to be smaller than the breakage probability, the link is assumed to be available. Each link is evaluated on whether it is available or not in each trial.

3.2 QOL evaluation

Firstly, available road links or facilities are led by a scenario which describes the reconstruction priority of damaged infrastructure. Based on a road network composed of available links in each phase, QOL index is calculated on GIS by the method introduced in the next chapter. The output image of QOL evaluation is shown in Figure 2. The average value

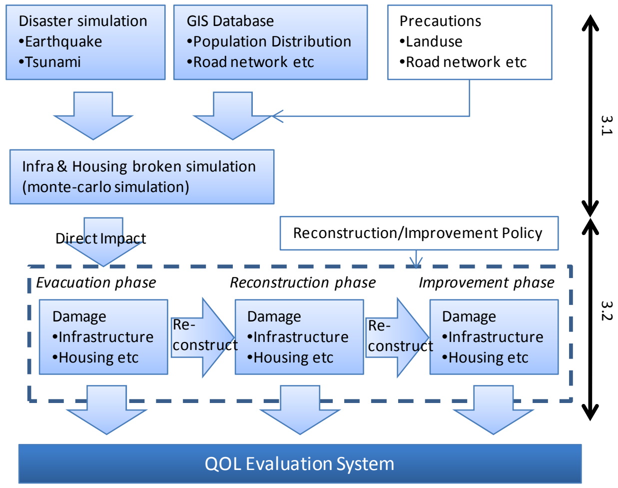

Figure 1: Framework of the system

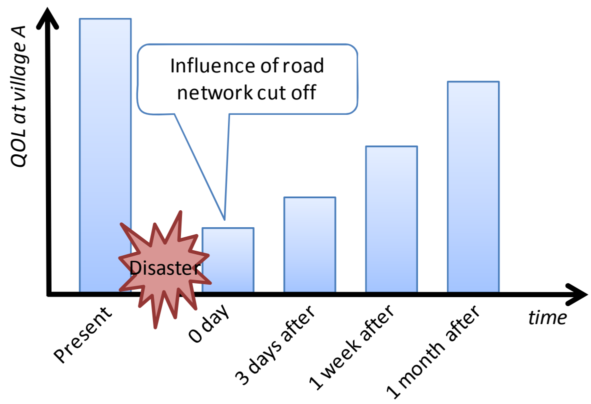

Figure 2: Output image

of 20 trials is set to the final QOL index in a village.

4. QOL EVALUATION SYSTEM

4.1 Basic system

The QOL indicator is designed by taking both the physical conditions in the residential areas and subjective sense of the residents into consideration. Firstly, as physical conditions, Life Prospects (LPs) consisting of Accessibility (AC), Amenity (AM), and Safety & Security (SS) is defined. The hierarchical structure of the LPs is shown in Table 2. As shown in eq. (1), the QOL indicator is quantified as a sum of the LPs weighted by subjective sense of residents. For weighting parameters, results of estimation by generation and by gender through conjoint analysis are used, based on a questionnaire survey on the selection of residential area[4].

$$QOL(g,i) = \mathbf{w}^T(g)\mathbf{LP}_S(i) \quad (2)$$

$$\mathbf{w}(g) = [w(g,AM), w(g,AM), w(g,SS)] \quad (3)$$

$$\mathbf{LP}_s(i) = [AC(i), AM(i), SS(i)] \quad (4)$$

$\mathbf{w}(g)$: weight parameter vector by attribute group g.

$\mathbf{LP}_s(i)$: Life Prospects vector in mesh i.

Measurement of QOL is the adopted QALY (Quality Adjusted Life Year) that is proposed in the field of health or environmental risk. QALY is the life years adjusted with QOL, and is expressed in units of "year" or "day".

4.2 Accessibility

AC, defined in equation (5) as potential type, represents the accessibility from residential area to main facilities.

$$AC_i = \sum_j^J \{AT_j \exp(-\alpha c_{ij})\} \quad (5)$$

AC_i: accessibility of zone i.

J: total number of zones composing the study area.

AT_j: attractiveness of facilities in zone j.

α : a parameter.

c_{ij} : generalized cost from zone i to zone j.

We apply the exponential function to diminish marginal cost. The parameter is estimated with OD trip distribution obtained from "Chukyo Person Trip Survey (2001)".

4.3 Application for disaster evaluation

In a disaster situation where survival conditions are threatened, the weighting parameter values of **w** in equation (2) are very different from the normal one. It is thought that the weighting parameter gradually shifts to its normal value through the evacuation phase, re-construction phase and improvement phase. The image is represented in Figure 3. Tendencies of the weighting parameter in each phase are described below.

Table 1: Components of QOL

Component	Detail of Component	Indicator
AC: Accessibility	Employment	Accessibility of Places of Work
	Education & Culture	Accessibility of Schools
	Health & Medical	Accessibility of Hospitals
	Shopping & Service	Accessibility of Shops
AM: Amenity	Living Space	Gross Floor Area for Living
	Townscape	Number of Building Stories
	Local Environmental Load	Green Space
	Neighborhood Natural Environment	Equivalent Sound Level
SS: Safety & Security	Earthquake-Generated Risk	Decrease in Life Expectancy Caused by Earthquake
	Flood Risk	Depth of water during flooding
	Risk of Crimes	Annual Crime Statistics
	Road Accident Risk	Number of Traffic Accidents

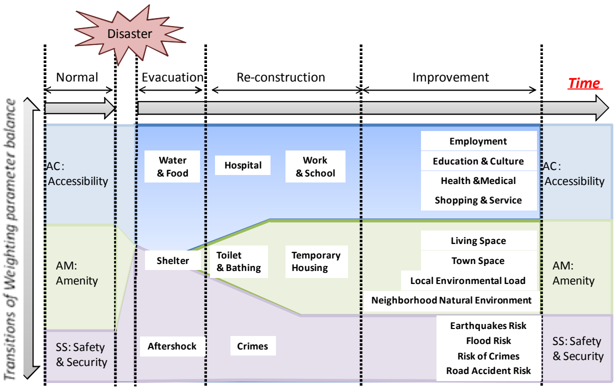

Figure 3: Changing of QOL weighting parameters post-disaster

- *Evacuation phase*: In the immediate post-disaster situation, accessibility to emergency evacuation facilities and medical facilities are attached greater importance. And, because of the cost of conveying supporting goods from other regions, importance is also attached to the quantity of food, water and blankets available in retail facilities or warehouses located in the disaster area. The status of the established evacuation site and the quantity of relief supplies having reached there are attached greater importance. In this phase, the conditions of sanitation such as toilet and bath are also regarded as important. Also, schemes for protection against secondary damage from aftershocks and peace preservation in the affected site are needed. Furthermore, safety information on missing family members and friends is also regarded as of importance.
- *Re-construction phase*: Amenity-related indexes such as the residential environment in temporary housing are regarded as important. Victims who are forced to live for a long time in poor surroundings need emotional support.
- *Improvement phase*: Offices and schools resume, and accessibility to these facilities are also regarded as important. Balances of the weighting parameter converge toward the normal value.

Table 2: Data

Data	Source
Road Network	Digital road map (2010, Japan Digital Road Map Association)
	Driving data (2011, Honda & Pioneer car navigation system)
Location of Hospitals	National Land Numerical Information Download Service (2005, Ministry of Land, Infrastructure, Transport and Tourism)
Seismic intensity in "Tokai-Sanrendou Earthquake"	Earthquake damage simulation tools (2009, Cabinet Office, Government of Japan)

To obtain the real weighting parameter, a questionnaire survey is planned at the assumed damage area from the "Tokai-Sanrendou Earthquake".

The above method makes it possible to describe the changing of QOL by village, considering both the physical urban conditions such as road network and the weighting parameter **w** that change as time goes.

5. CASE STUDY

5.1 Case study area and data

Case studies have been conducted on the Tohoku region (Iwate and Miyagi prefectures) and the Tokai region (Shizuoka, Aichi and Mie prefectures). In the Tohoku case study, the damage from "The Great East Japan Earthquake" is evaluated, while in the Tokai case study "Tokai-Sanrendou Earthquake" is assumed as the target disaster. Here, QOL has been estimated with only AC to hospital which is the most important QOL factor immediately after disaster strikes. Tohoku's estimation was based on the actual data, but in the Tokai area the damage predicted by the earthquake damage prediction tool was used in the absence of actual data. Table 2 shows the data used. In addition, hospitals flooded by tsunami were assumed to lose their ability to function. For "The Great East Japan Earthquake", we used actual data. For the "Tokai-Sanrendou Earthquake", we applied the assumption that areas within 10 km from the coast and up to 10 meters above the sea level would be flooded.

5.2 Result of analysis

a) The Great East Japan Earthquake

Figure 4 describes the decrease rate of AC to hospital compared to normal AC by municipality after "The Great East Japan Earthquake (11 March 2011)".

This research has used recorded car driving information from car navigation systems; even those roads that may have been motorable but were not recorded have been regarded as not motorable. Hence this AC result could be undervalued.

Immediately after the earthquake (March 13th), AC had decreased in whole, especially in the Sanriku coastal area. However, the decreasing rates in urban areas such as Sendai city and Morioka city were comparatively less, and in some coastal areas the decrement was suppressed differently because the hospitals in these areas were located on higher ground and were unaffected by the tsunami. Meanwhile, disconnecting Route 45 which runs through the Sanriku coastal area resulted in complicating access to the surviving hospitals. As a result, the gap in AC among regions widened.

One week after the earthquake (March 18th), most regions had regained AC, especially areas along the Tohoku road connecting to Sendai city or Morioka city. Additionally, recovery in Miyagi prefecture, especially of Sendai city, is bigger than that of Iwate prefecture.

One month later (April 11th), areas along Tohoku road had recovered further; however, there were still some municipalities at less than 20% of their normal level.

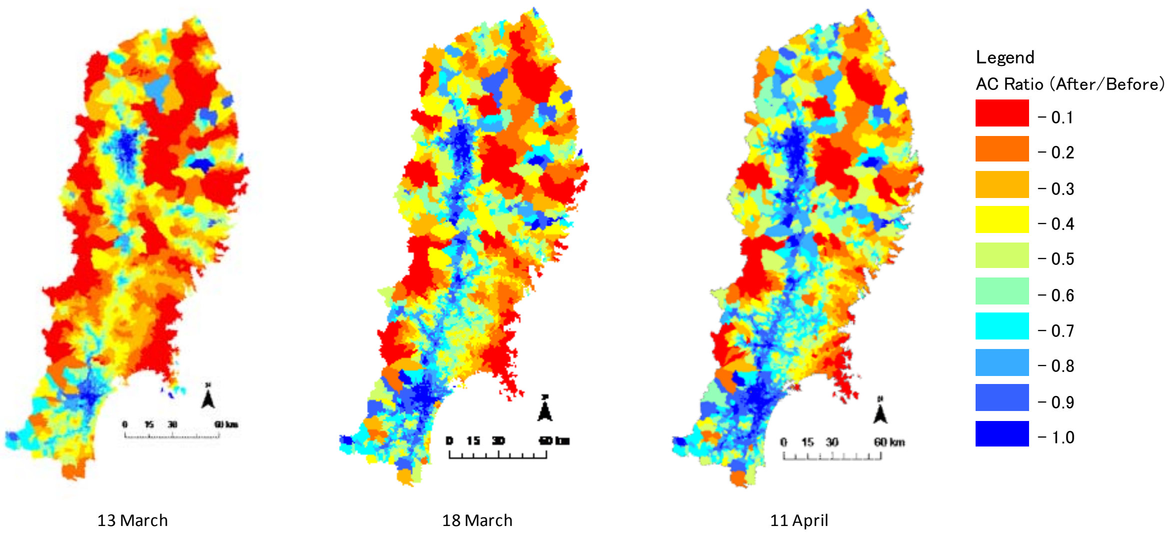

Figure 4: Time series AC transition in Tohoku region

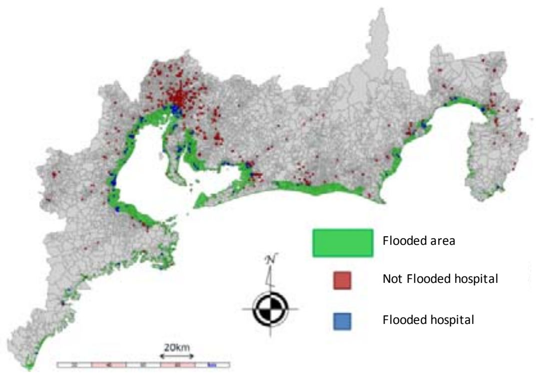

Figure 5: Assumed tsunami damage area and hospital location in Tokai region

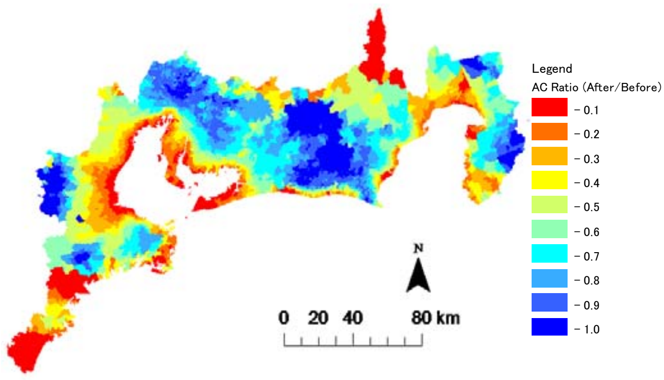

Figure 6: AC transition at 0 days after disaster in Tokai region

b) Tokai-Sanrendou earthquake

Figure 5 describes flooded areas from tsunami and locations of hospitals. The green parts indicate flooded areas and the blue parts refer to hospitals that have lost their ability to function. From this figure, severe damage in coastal areas is anticipated. Figure 6 describes the ratio of AC between pre-disaster and post-disaster situations. As this figure shows, AC decrease rate in coastal areas that lost hospital functionality due to tsunami is significant. In contrast, the AC remains at a high level in regions around Nagoya city which have intensive road networks. These results show trends similar to the estimation in the Tohoku area.

6. CONCLUSION

6.1 Consideration

This study established a system to evaluate disaster damage from the viewpoint of residents' QOL. We apply this system to the Tohoku and Tokai areas, focusing on AC to hospital, which is one of the most important factors immediately after disaster strikes. The findings are as follows:

a) In "The Great East Japan Earthquake", AC was greatly decreased along the Sanriku shoreline which suffered severe damage. On the other hand, in some inland areas decrease of AC was suppressed.
b) Meanwhile, from time series comparison, recovery in AC has also been observed. The recovery is particularly remarkable in the central area of Sendai city which has a rich road network.
c) The analysis on the "Tokai-Sanrendou Earthquake" anticipated in the Tokai area reveals that AC in coastal areas was greatly decreased because of collapse of the road network and decrease in hospital functioning. On the other hand, the decrement was suppressed in some urban areas such as Nagoya where many hospitals and tight road networks existed.
d) This result shows a similar trend to AC changes in the case study on "The Great East Japan Earthquake". This indicates the need for rapid analyses of the effects of the "Tokai-Sanrendou Earthquake" on the Tokai area.

Countermeasures against earthquakes need to be implemented in the Tokai area: Medical facilities in coastal areas will need to be protected from tsunamis. Also since urban areas show rapid AC recovery after earthquakes, construction and maintenance of roads will contribute to suppressing decrease in AC after an earthquake.

6.2 Future works

Future works are as follows:

a) There is a need to consider the probability of collapse of not only road networks but also of institutions.

b) Concretization of the most appropriate road construction to maintain and recover AC after earthquakes, and analyses of AC change over time, are also necessary.

c) Influence evaluations based on more comprehensive QOL indicators that include amenity or security and safety will contribute to improvement of future disaster management.

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