Evaluation of Living Environment for Refugees after the Great East Japan Earthquake in each Detailed District

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Abstract

This study aims to establish a system to evaluate the post-disaster living environment for refugees in each small district as "Quality of Life (QOL)" by a time series. Taking the physical conditions of the residential areas and needs of the refugees into consideration, we evaluated the QOL phases in the Tohoku coastal area that suffered severe damage from The Great East Japan Earthquake on 11 March 2011.The following results were obtained: 1) It was shown that improvement in the redundancy of a road network contributes to the maintenance and improvement in QOL immediately after the disaster. 2) It became clear that the damage to lifelines or facilities in the coastal area has had a long-term influence on the decline of QOL.

1. Introduction

The Great East Japan Earthquake, which occurred on 11 March 2011 is the most powerful earthquake on record in Japan.

Many people were victimized by a tsunami of over 10 meters which was triggered by this earthquake and crashed into the north-east coast. Additionally, much infrastructure, such as roads, power supply, power plants and disaster-prevention facilities were destroyed by tsunami. This damaged infrastructure inhibited post-disaster evacuation and rescue activities and many disaster refugees had to take shelter in uncomfortable surroundings for long periods with a food supply shortage.

In examining proactive measures against future disasters, it is necessary to discuss measures not only to decrease the number of people killed or injured but also to maintain refugees' living standards. Therefore, measures to avoid isolation through transport network redundancy and adaptation measures such as preparing evacuation shelters are required.

Following a disaster, refugees' needs and the need for infrastructure vary from hour to hour. Therefore, the effects of damage control measures taken before and after the disaster should be evaluated from the immediate aftermath through restoration in each area. Also, it is necessary to define priorities for maintaining refugees' living standards.

This study aims to establish a system to evaluate the post-disaster living environment for refugees in each small district as "Quality of Life (QOL)" by a time series. This system can define priorities for damage control measures both before and after the disaster to maintain QOL for refugees.

2. Damage conditions in the Great East Japan Earthquake

The Great East Japan Earthquake struck the Tohoku district. The damage extended over a broad area. Especially in Iwate and Miyagi Prefectures, tsunami and earthquake motion wreaked enormous damage. This study covers these areas.

Populations (2005) of the two prefectures are about 2.35 and 1.33 million respectively (Table 1). The population is concentrated in the Kitakami Basin, the inland area of Iwate Prefecture, and Sendai City, the biggest city of Miyagi Prefecture (Figure 1). Both prefectures have suffered from tsunamis on the Pacific side since olden days: Meiji Sanriku Earthquake (1896), Showa Sanriku Earthquake (1933), Chilly Earthquake (1960), etc.

People in these areas have taken countermeasures each time, such as moving upland and preparing big coastal levees. But these areas suffered a great deal of damage again in the Great East Japan Earthquake. Damage from both the earthquake and the tsunami were serious.

Table 1. Damage in the Great East Japan Earthquake by geographical area

	Iwate	Miyagi	Entire country
Population (2005)	1,330,147	2,348,165	
Area (km^2)	15,278.89	7,285.76	
Dead or missing*[1]	5,844	10,849	18,580
Total damage (billion yen)*[2]			About 16,900

*[1] National Police Agency, Damage situation and Police measure of the Great East Japan Earthquake, Retrieved February 15, 2013 from http://www.npa.go.jp/archive/keibi/biki/higaijokyo.pdf

*[2] Cabinet Office, June 24, 2011, The estimation of the amount of damage by the Great East Japan Earthquake, Retrieved February 15, 2013 from http://www.bousai.go.jp/oshirase/h23/110624-1kisya.pdf

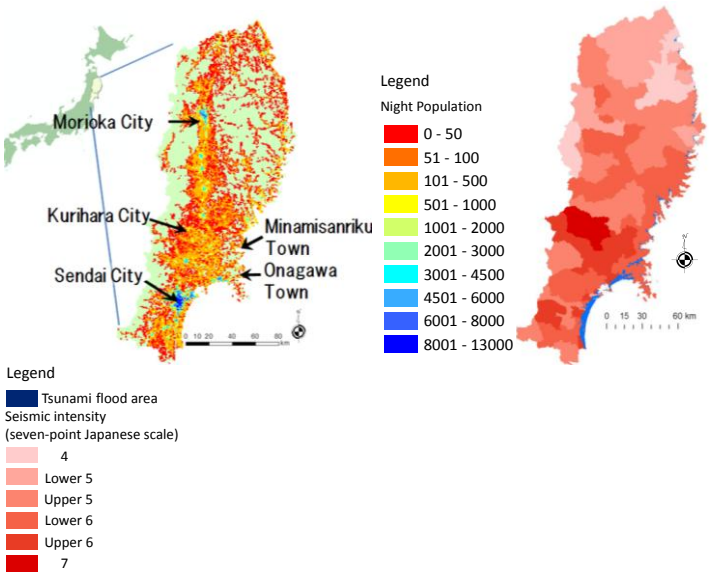

Fig. 1. (left) Population by geographical areas, (right) Distribution of seismic intensity and tsunami flood area in the Great East Japan Earthquake

As shown in Table 1, "direct damage" of the Great East Japan Earthquake, such as human suffering and physical damage and recovery costs of infrastructure facilities, was enormous. The number of deaths was over 18,000 people across the country, and the total damage to buildings and infrastructure was close to 17 trillion yen.

On the other hand, "indirect damage", such as the impact on the economy due to dysfunction of the infrastructure and facilities and worsening of living conditions of refugees, became a huge problem. A number of problems occurred, such as disruptions of the supply chain for economic activities. For the living environment of refugees, there was an increase in deaths associated with cold, hunger and reduced medical services, health and environmental degradation, and a lack of privacy associated with long-term shelter life.

Table 2 shows the needs of refugees in a time series, with information drawn from newspaper articles after the Great East Japan Earthquake and questionnaire surveys for refugees of past disasters (Tsunapro, 2011; Survey Research Center, 2007; and Joh, 1995).

According to the above information, the needs of refugees are changing as time goes by. Immediately after the earthquake, needs for life maintenance are greatest, but as time passes, hygienic needs increase, and finally returning to the prior level of social life takes priority.

In this way, needs of refugees are changing every moment from immediately after the disaster occurs. So, preparatory countermeasures for supporting these needs to enable them to bounce back to the prior level of social life at an early date, and follow-up systems immediately after the disaster are desired.

Table 2. Time series needs of refugees

Time	Needs of refugees	
Immediately after the disaster	Accessibility of emergency shelter or health-care center, food, drinkable water, provision against the cold in shelter Opening of shelter and supply of food and drink, etc.	Life maintenance
Evacuation phase (short term)	Sanitary conditions of the toilet, development of bathing facilities, ensuring change of clothes Fear of secondary disasters caused by after-shocks, information such as on safety of family members	Hygienic environment

Evacuation phase (long term)	Ensure privacy, improvement of sanitary conditions, suppression of infection	Good hygiene environment
Recovery phase	Moving into temporary housing, securing means of transportation to resume work or school	To have a social life

3. Researches regarding the living environment in disasters

3.1. Researches regarding normal living environment

Regarding the evaluation of the living environment in normal times, in Western countries which matured economically earlier than Japan, emphasis was shifted very early toward improving the individual quality of life (QOL). QOL is a concept revealing how well individuals can expect to live. It is also said to be the degree of self-realization decided by individual imagination (value judgment), and opportunities and ability (environmental characters) for achievement.

As an example of research discussing urban policy aimed at improving QOL, Myers (1988) defined QOL as a grade of comfort measured by the physical environment and individual preference. And he suggested the need to examine urban planning regarding QOL. Ulengin et al. (2001) conducted a questionnaire survey about QOL. Ecket et al. (2005) examined the impact of land-use and transportation on individual QOL and suggested that residential planning considering life-styles was needed.

Then Kachi et al. (2006) evaluated QOL as district units. It is an approach by which is possible to evaluate QOL in normal times quantitatively by multiplying the residential environment and residents' preferences corresponding to it.

As above, regarding the evaluation of living environment in normal times, a comprehensive and quantitative evaluation approach could be developed considering the environment around residents and individual value judgment. But these approaches are generally for normal times, especially focusing on the improvement of amenities in developed countries, so that it is difficult to evaluate an emerging situation when all things, including lives, are in a state of disaster, and the needs of refugees, which are changing all the time, by the same method.

Meanwhile, QOL evaluation is not only a subjective evaluation of consumers such as “satisfied, sufficient, not satisfied, anxious”, but also includes a process to figure out factors causing that result and evaluate them as “good” or “bad”. So QOL evaluation can be used for the relationship between the needs of refugees and the physical environment, which is the purpose of this study (in other words, the situation in which life conditions are threatened while refugees’ needs are changing significantly in emergencies, and changing all the time, according to the sufficiency of the infrastructure).

3.2. Researches regarding effects of disasters on refugees’ living environment

Previous researches regarding effects of disasters on refugees’ living environment have been mainly of three types:

a) Researches regarding changes of the living environment surrounding refugees

b) Researches regarding mental changes of refugees

c) Researches considering both the environmental changes of life and mental changes

a) As for researches focusing on the living environment of refugees and infrastructure damage, many approaches relating to a single type of infrastructure have been performed. Kondo et al. (2010) evaluated the number of days villages were isolated due to blocked roads and Ota et al. (2008) evaluated food self-sufficiency of isolated villages. Chang and Nojima (2001) measured post-disaster transportation system performance. Fernando et al. (2009) illustrate in detail the challenges faced in providing water and sanitation facilities in various phases. Menoni et al. (2002) developed a model to evaluate the seismic vulnerability of lifelines such as water, power, gas and communications. Johnson (2007) focuses on temporary housing after disasters; his research is an attempt to demonstrate that the factors affecting temporary housing programs come both from the system of temporary housing and from larger systems.

However, these approaches cannot be used to compare the priority of countermeasures with that of other types of infrastructure.

b) As for researches focusing on mental changes of refugees, there are some advocating the necessity of support corresponding to changing needs, such as an interview survey of refugees in the Hanshin Awaji Earthquake (Joh, 1995) and a questionnaire survey of refugees in the Chuetsu Earthquake (Matsui, 2005).

c) In the researches considering both environmental changes and mental changes, there is one arranging the relationship between change of needs and infrastructure recovery over refugees' time series (Tsukamoto and Hatoko, 1997). But the arrangement is no more than a qualitative evaluation. As attempts at quantitative evaluation, Imura and Ishikawa (1996) focus on the spatial performance and change of needs of the residence refugees chose, and Nojima et al. (1993) and Shiono et al. (1995) evaluate the life line performance and changes in refugees' needs. However, because they are just analyses focusing on causal relationships between changes in needs and specific infrastructure one by one, analysis of interrelationships, such as accessibility of shopping and hospitals during transportation network reconstruction and the performance of the infrastructure during the recovery of electricity and gas, is impossible. Therefore, it is necessary to build an integrated evaluation method including the relationship with the recovery of each type of infrastructure.

Togawa et al. (2011) designed a QOL indicator for disaster situations, taking the physical conditions of the residential areas and the subjective sense of the residents into consideration. In this research, although the large framework of the system is shown, the analysis only relates to the decline of accessibility (needs change cannot be analyzed).

3.3. Perception of the evaluation of living environment in this study

From the above, this study uses the QOL method to evaluate the living environment of refugees in emergencies. In this study, the definition of QOL is set as how much the people in that environment can widen their opportunities and possibilities (width of selection) (Shimizu, 1998).

This study evaluates at the regional level considering both a) needs appearing at one time, and b) the surrounding environment, such as infrastructure corresponding to the needs, upon the assumption that the value judgment (needs) of the QOL is particular to each person at first.

4. Methodology for quantifying life level in a disaster

4.1. Structure of QOL for refugees

In this section, we explain our assumptions for estimating QOL for refugees, which changes in phases after a disaster. We apply an idea of cycles

for satisfying daily needs (Nojima et al., 1993). In the research, the basic structure of needs for normal living is classified as below:

1. Requirements for maintaining life
   (food, sleep, etc.: hour-day cycle)
2. Requirements for maintaining health or public health
   (bathing, cleaning, etc.: day-week cycle)
3. Requirements for social life
   (work, education, etc.: day-week cycle)
4. Requirements for cultural life
   (hobby, rest for mental condition, etc.: week-month cycle)

The shorter the cycle is, the more necessary is the factor. And, as shown in Table 2, shorter cycle items would be revealed in a short period. Based on the above conditions, the structure of QOL for refugees after a disaster has a hierarchical structure that corresponds to the living environment and the elapsed time, which is based on refugees' psychological impression. More specifically, we assume that the QOL structure in a disaster consists of 4 phases: Phase 1: maintenance of life, Phase 2: maintenance of health or public health, Phase 3: maintenance of a social life, Phase 4: maintenance of cultural life.

4.2. Basic structure of disaster QOL evaluation system

Figure 3 shows the basic structure of the disaster QOL evaluation system. In the system, QOL is derived from the transition of refugees' needs (QOL elements) and infrastructure recovery condition after disaster.

The concrete process is below. First, a) infrastructure and building availability are evaluated by real data or simulation and recovery data after a disaster. Based on the situation, b) satisfaction of each QOL element is judged. Finally, c) QOL is divided into 4 phases based on whether or not it has reached each QOL judging level, and QOL phases are judged in each individual district. Then, QOL phases are output for each small district.

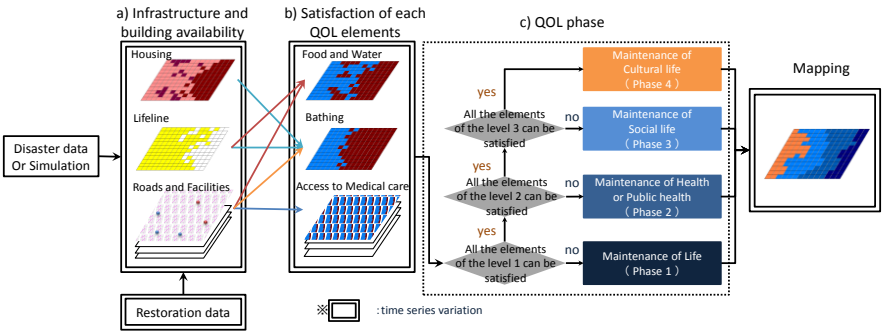

Fig. 3. Basic structure of disaster QOL evaluation system

4.3. Judgement of satisfaction condition

Satisfaction conditions of QOL elements in each small district are based on infrastructre requirements that are necessary for supplying coresponding services or goods. There are two types of QOL elements: 1) satisfied within the residential area, and 2) requires transportation. Each satisfaction condition is described below (Figure 5):

1) QOL elements satisfied in the residental area

It is judged as satisfied if all infrastructure supporting QOL elements is available.

2) QOL elements satisfied by transportation

a) Identifing reachable area from the residential area considering road and public transportation connectivity

b) If one's destination is located in the reachable area, the element is judged as satisfied.

For example, for ensuring "opportunity for bathing" (satisfaction of need for bathing) at least one of the below conditions should be functioning normally:

A combination of "bathing facilities" and "transportation"

A combination of "lifeline (gas and water) " and "housing".

This relationship is formulated as shown in Equation 4.1.

$$y = (x_1 \wedge x_2) \vee (x_3 \wedge x_4) \tag{4.1}$$

where, y: opportunity of bathing, x_1: housing, x_2: lifeline (gas and water), x_3: transpiration, x_4: bathing facility. If present, the variable is set to 1, otherwise it is set to 0.

And, as for recovery of facilities, roads and transportation systems, the area where QOL elements are satisfied would be expanding.

Finally, the judgement conditions for satisfaction of QOL elements that can be satisfied with help from other regions are as follows. We suppose that a support base is located on road within the boundary of the target region (Iwate and Miyagi), and the reachable area from the support base is judged as the supportable area.

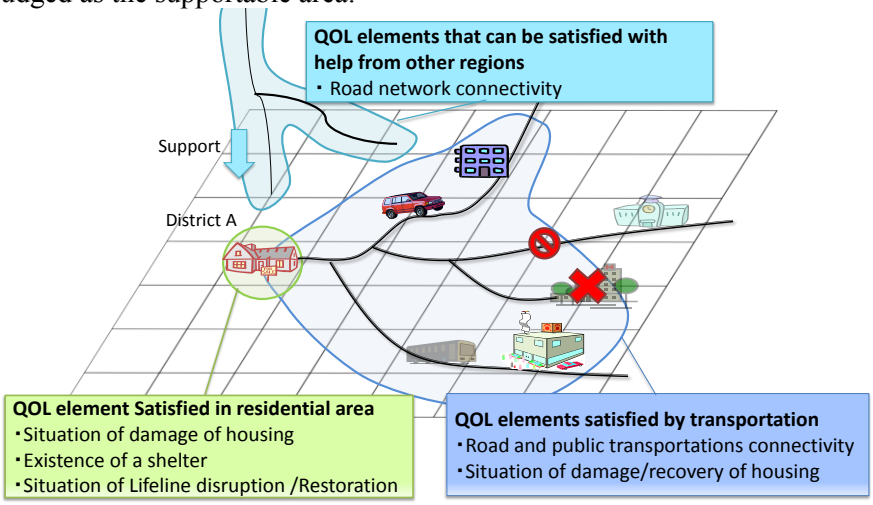

Fig. 4. Satisfaction conditions of QOL elements

4.4. Extraction of index

The index is extracted based on a questionnaire survey to refugees of past disasters (Tsunapro, 2011; Survey Research Center, 2007; and Joh, 1995). In Table 3, QOL elements and their satisfaction conditions (combination of required infrastructure) are shown.

Table 3. QOL elements and their satisfaction conditions

		QOL element (opportunity or environment)	Satisfied in residenntal area	Satisfied by transportation	Satisfied with help from other regions	Judgment method (required infrastructure)
1		Emergency care		○	○	(Medical Facilities ∧[*1] Transportation[*3]) ∨[*2] Help from other regions
	△	Medicine	○	○	○	Stock ∨ (Drugstore ∧ Transportation) ∨ Help from other regions
		Drinking Water	○	○	○	(Housing ∧ Running water) ∨ (Transportation ∧ Transportation) ∨Help from other regions
		Food (quantity)	○	○	○	(Shopping facility ∧ Transportation) ∨ Help from other regions
		Sleeping Place	○	○	○	Housing ∨ Shelter
		Protection against Cold	○	○	○	(Housing ∨ Shelter) ∧ (Heating Energy ∨ Blanket)
2		Medical care		○	○	(Medical Facilities ∧ Transportation) ∨ Extraordinary clinic
		Food (quality)	○	○		(Shopping facility ∧ Transportation) ∧ Lifeline
		Bathing	○	○	○	(Housing∧Lifeline) ∨ ((Bathing facilities ∨ Temporary bathing facilities) ∧ Transportation))
		Toilet	○			Toilet ∧ Wter and sewerage
		Clean Clothing	○	○	○	(Housing∧Running Water) ∨ (Shopping facility ∧ Transportation) ∨ Help from other regions
	△	Fresh Air	○			Equipment for ventilation
		Thermal environment	○			Refrigeration and heating equipment ∧ Lifeline
		Privacy protection	○	○		(Housing ∨ Temporary housing ∨ (Shelter ∧ Partitions)
3		Education		○		School ∧ Transportation
	△	Employment		○		Workplace ∧ Transportation
		Shopping		○		Shopping facility ∧ Transportation
		Residential Housing	○			(Housing ∧ Lifeline) ∨ Temporary housing
4	□	Accessibility	○	○		QOL Evaluation System (Kachi et al, 2006)
	□	Amenity	○			
	□	Safety & Security	○			

△: necessary to consider (not considered in this study)

□: not necessary to evaluate in this study

*1 ∧: logical conjunction or meet in a lattice

ex) The statement A ∧ B is true if A and B are both true; else it is false

*2 ∨: logical disjunction or join in a lattice

ex) The statement A ∨ B is true if A or B (or both) are true; if both are false, the statement is false

*3 Transportation includes road network, car, bus, train and gasoline

Table 4. Data showing the disaster situation

Data	Source
Road Network (in normal times)	ArcGIS Data Collection 2011(ESRI JAPAN)
Road Network Recovery	Driving data (2011, Honda & Pioneer or Toyota car navigation system)
Tsunami flood area	ESRI JAPAN
Medical facilities (in normal times)	National Land Numerical Information Download Service (2005, Ministry of Land, Infrastructure, Transport and Tourism)
Medical facilities recovery	The Portal Map for Rescuing Disaster Areas (based on Google Map), Kahoku online network
Shopping facilities	ArcGIS Data Collection 2011 (ESRI JAPAN)
Shopping facilities recovery	The Portal Map for Rescuing Disaster Areas (based on Google Map), Kahoku online network
Temporary housing	The Civil Construction Division, Miyagi Prefecture, Construction location of emergency temporary housing in Iwate Prefecture (based on Google Maps)
Water service restoration	Ministry of Health, Labour and Welfare, Japan
Gas service restoration	Japan Gas Association HP, Ministry of Economy, Trade and Industry, Agency of Natural Resources and Energy, Natural Resources and Fuel Department, Oil Distribution Division
Bathing institution (in normal times)	ArcGIS Data Collection 2011 (ESRI JAPAN)
Bathing institution	The Portal Map for Rescuing Disaster Areas (based on Google Maps)
Temporary Bathing institution	The Portal Map for Rescuing Disaster Areas (based on Google Map)
Gas station (in normal times)	ArcGIS Data Collection 2011 (ESRI JAPAN)
Gas station opening situation	The Portal Map for Rescuing Disaster Areas (based on Google Maps)
School (in normal times)	National Land Numerical Information Download Service (2005, Ministry of Land, Infrastructure, Transport and Tourism)

4.5. Data and judgments of satisfaction condition for evaluation

Data used for analysis is shown in Table 4.

For evaluation, we process and organize the data in accordance with the framework of the evaluation of the previous section. First, we use recovery condition data after a disaster on a priority basis. If we cannot obtain the

data, we assume that the tsunami inundation area is suffering outage and the outside this area has no damage. However, we corrected the damage level for facilities in a regional flood based on information such as news, since the data that we use includes areas with low-level damage as well as areas with enormous damage. Also, for such information as restoration of lifeline conditions, the data which is reported in units of municipalities, was allocated to the the district (offshore tsunami) in in accordance with the rate of recovery. Similarly, the number of deaths was assigned to the mesh belonging to the tsunami inundation area damage information for each municipality.

The quantity of food, water and sleeping places is not taken into consideration. So it is judged as satisfied if all of the infrastructure that supports QOL elements is available, even if not available for the whole population.

In addition, the reachable area in the event of the disaster was set by the following procedure:

1) Exclude the mesh which had a population of fewer than 10 people before the disaster occurs. Then calculate the shortest time from other districts to each destination facility by Network calculation using the data in normal times (using motor vehicles).

2) Maximum reachable time in all mesh is assumed to be the limit conditon.

3) In a disaster, if the shortest time to the destination considering road conditions and facility availability is less than the limit value set by 2), the district is judged as reachable.

5. Results of analysis

We analyzed the following three cases:

(1) Situation considering support (help from other regions)
(Close to The Great East Japan Earthquake situation)

(2) Situation without considering support (help from other regions)

(3) Situation with all the Sanriku coast freeway opened to traffic

The result of (1) is shown first and is compared with the result of (2). The result (1) clears the self-supporting area even if there is no support. It can clarify the knowledge that will become useful in the case of investigation of priority attachment of disaster response.

Then, comparing (3) and (1), we analyzed the effect of constructing road infrastructure as an advance measure to decrease QOL attrition.

5.1. Situation with considering support (Close to The Great East Japan Earthquake situation)

5.1.1. Transition of QOL phases

Figure 5 shows the transition of QOL phases from 14 March to 11 May 2011 in each district after "The Great East Japan Earthquake (11 March 2011)"

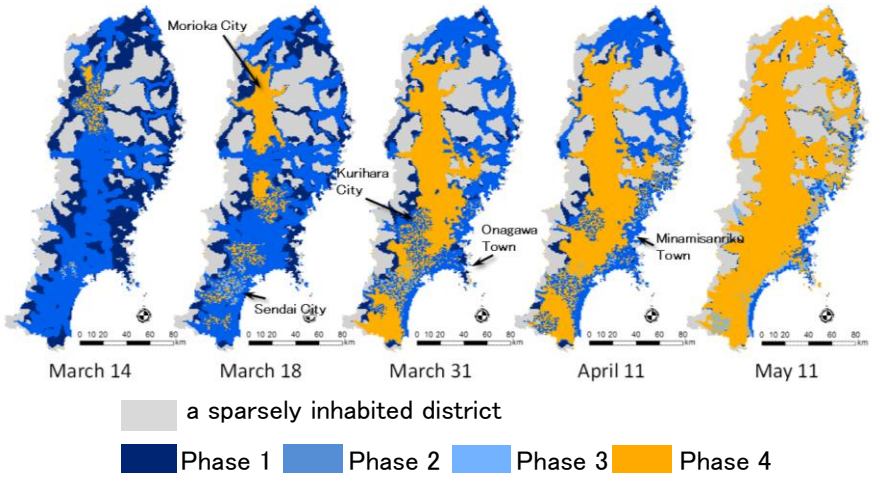

Fig. 5. Transition of QOL phases

The trend of the total recovery of QOL in the inland area is earlier than in the coastal area due to serious infrastructure destruction by tsunami damage in coastal area.

First, we focus on the coastal area. On March 14 (the third day after the disaster), QOL was recovered in some areas from phase 1 (the lowest) to phase 2 by reviving the function of road infrastructure connecting to the inland. This can be seen as an effect of "Kushinoha Sakusen" which is a strategy for recovering road functions quickly to make various routes co-operating with the Self-Defense Forces following and sticking to the coastal area where serious damage is assumed owing to tsunami damage. However, many districts were still in phase 1 in the coastal area of northern Miyagi Prefecture on March 18. Especially, Onagawa town located on the Oshika Peninsula in Miyagi Prefecture was even at phase 1 until March 31. The QOL phase is low in the long term. Also, on May 11 (two months after the disaster), in Minamisanriku town, Miyagi Prefecture, almost the entire town recovered to phase 2. This town began to discuss moving a

group shelter from near the coastal area to an inland area from March 26, and between April and the beginning of May, the refugees had a group shelter inland. What this example makes clear is that to avoid such confusion, they should examine a group shelter beforehand, and it is necessary to plan how to form agreement among inhabitants in the districts where the QOL phase is lower after suffering over a long term.

On May 11 (two months after the disaster), many districts had recovered to phase 2. Here, compared with the tsunami flood area (Figure 2), we realize that the area of phase 2 on April 11 is larger than that of the tsunami flood. It means that even if there is no direct damage to a house by tsunami flood, the quality of the living environment for refugees falls greatly in the long term, because important institutions including supermarkets and hospitals have been damaged and the main road on low-lying coastal land has been closed by the tsunami. In addition, the damage to lifelines such as water and sewage facilities makes the quality of the living environment decline over a huge area extending to the whole supply district.

Second, we focus on the inland area. In Kurihara City, Iwate Prefecture, which is an area that recorded seismic intensity 7, the recovery speed of the QOL is slow, because the recovery rate of the water service covering the whole city was low. It caused not only the hygiene environment of the restrooms to become worse, but also the refugees were not able to bathe.

Comparing Morioka City, a metropolitan area in Iwate Prefecture and Sendai City which is also a metropolitan area, in Miyagi Prefecture, it followed that recovery of the QOL was earlier in Morioka City than in Sendai City due to the delay of recovering the entire piping network service of city gas. On the other hand, in Morioka City, many houses use LP gas. The merit of using LP gas is that it is easy to recover gas service by changing gas tanks individually. After the disaster, this supported quick recovery. However, in this paper, we have not been able to consider the employment opportunities after disaster. Please notice that very few areas reached phase 3 (phase of maintenance of a social life).

5.1.2. The population transition in each district at different QOL phases

Figure 6 shows transition of the population belonging to each QOL phase. The method of counting the population in this case assumes that refugees keep living in the same district where they lived before disaster.

Not only the refugees who are in the refuge, but also those in their own houses are forced to live inconvenient lives by the damage to the lifelines or the cutting off of the transportation network. But, their needs for government and voluntary support are different according to their QOL phase.

Therefore, counting the number of refugees based on the QOL phase will help to decrease the mismatching of support between the refugee and government or volunteer support. From Figure 8, until March 31, the QOL phase for the refugees was improved. But on April 11 the trend was changed due to a big aftershock on April 7.

When comparing the inland area with the coastal area, the refugees in areas in a low QOL phase decreased sharply, because the convenience of movement improved by restoring traffic on the roads which were interrupted. Furthermore, an early restoration of convenient facilities such as supermarkets around their houses or refuges also improved their QOL phase. Even in the coastal area, the number of refugees in phase 1 has been decreased over time. However, the improvement to a higher QOL phase does not progress, and it remains in the same phase after May 11. The reason is that restoration of the infrastructure damaged by the tsunami has taken a long time.

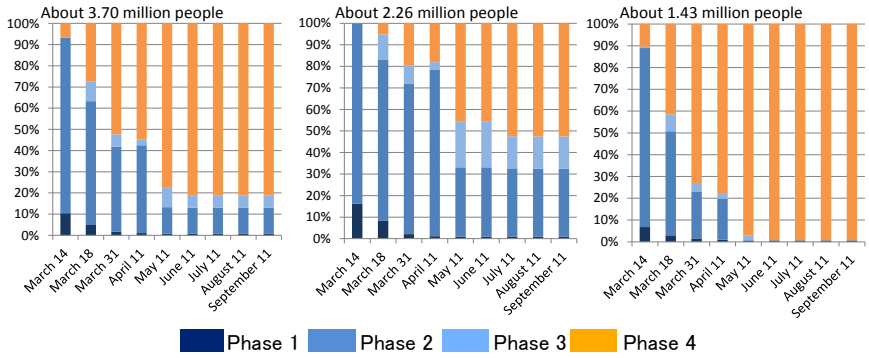

Fig. 6. Transition in the number of refugees belonging to each QOL phase (Left) whole region, (center) inland area, (right) coastal area

5.2. Situation without considering support

In Chapter 5.1, QOL is calculated following the assumptions that if the damaged area could connect with other regions by road, the refugees could satisfy their need for goods and that means their QOL would then rise. However, goods to support the refugees cannot necessarily be delivered just because the area was connected with other areas when the damaged area is huge. In fact, during the "Eastern Japan Great Earthquake", the shortage of gasoline constrained transportation for delivering support goods into the damaged area. In this study, this situation is called "without support situation". Here a calculation of QOL is given considering no sup-

port. A comparison of the transition of QOL phases (one week after the disaster) between the situations with support and without support is displayed in Figure 7.

On March 14 (the third day after the disaster), it is obvious that the coastal areas in phase 1 with support expanded more widely than those without support. This result means that the "Kushinoha Sakusen" mentioned in the Chapter 5.1 could raise the QOL phase from the bottom up compared with the case of no support from other regions.

On March 18 (seven days after the disaster), areas that had recovered up to phase 2 without support were extending, but still there were many areas still in phase 1 in the coastal area. However, there were also some districts along the coast that had recovered to the same level as those receiving support. From the above, it is possible to identify self-supporting areas where the roads are well-connected so that they can receive support from others or help themselves.

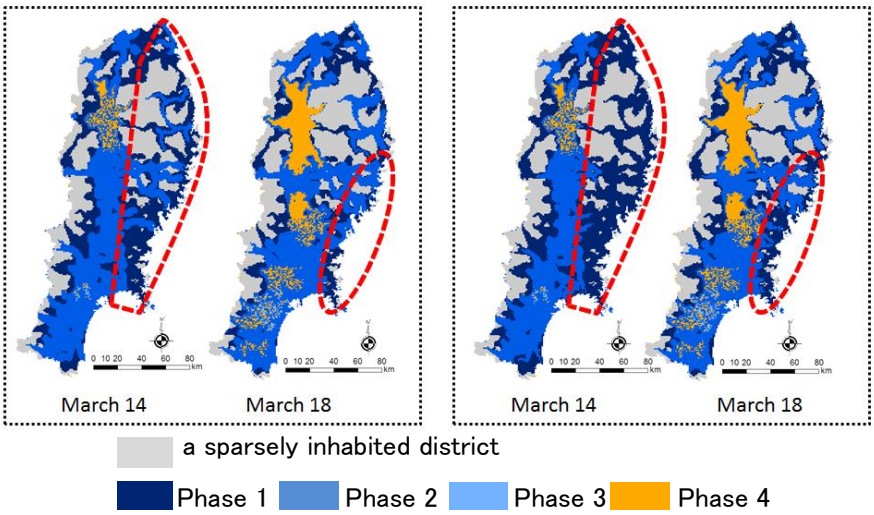

Fig. 7. Transition of QOL phases. (Left) With support, (Right) Without support

Figure 8 shows the transition of the number of refugees belonging to each QOL phase under the situations of with support and without. Without support, the population belonging to phase 1 on March 14 is predicted to increase by about 10% (around 350,000). This reveals the number of refugees when material and medical support cannot be actually delivered from outside, even though road access to the other regions is complete. Especially, when limited resources cannot be transported to the disaster areas, it could support making it a high priority.

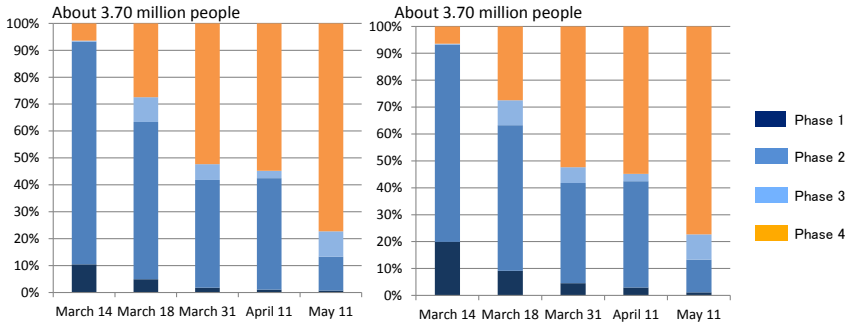

Fig. 8. Transition of the number of refugees belonging to each QOL phase. (Left) With support, and (Right) Without

5.3. Situation in which the Sanriku Coastal Freeway was opened to traffic

The Sanriku Coastal Freeway is under construction on high ground considering the tsunami disaster. It is expected to contribute as an emergency road for residents' evacuation. This study calculates the QOL phase under the assumptions that the whole freeway which has been planned is opened and is without any damage. Figure 9 shows the location of the Sanriku Coastal Freeway.

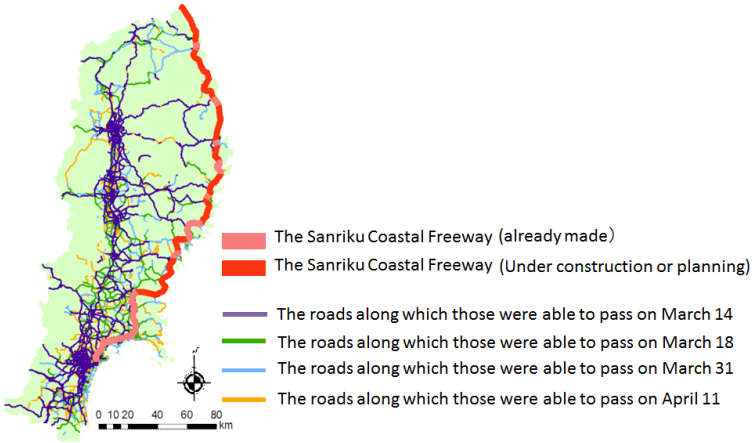

Fig. 9. Location of the Sanriku Coastal Freeway

Figure 10 shows a comparison of transition of QOL phases (one week after the disaster) in each area between the real situations (with the Sanriku

Coastal Freeway partly available) and the case when the whole road is totally available. In the real situation, the QOL phase of the Sanriku coastal area reached only phase 1 on March 14. On the other hand, in the case with the whole Sanriku road available, the QOL phase recovered up to phase 2 on the same day. From Figure 11, in the same case, it is clear that the population at phase 1 decreased by about 8.5% (around 120,000 people) by March 14. This shows that the Sanriku Coastal Freeway functioned as an emergency road after the disaster. But the difference between the partly-functioning case and the totally-functioning case is small until one week after the disaster. This is because houses and convenience facilities were destroyed by the tsunami so that it is quite difficult to have a self-supporting life in the districts, even if the whole road is available.

From the above, though reinforcement of the road network is useful to maintain and improve QOL after a disaster, it is necessary to implement countermeasures such as raising the safety of facilities in target areas and avoiding functional deterioration to suppress a decline in QOL in the medium and long terms.

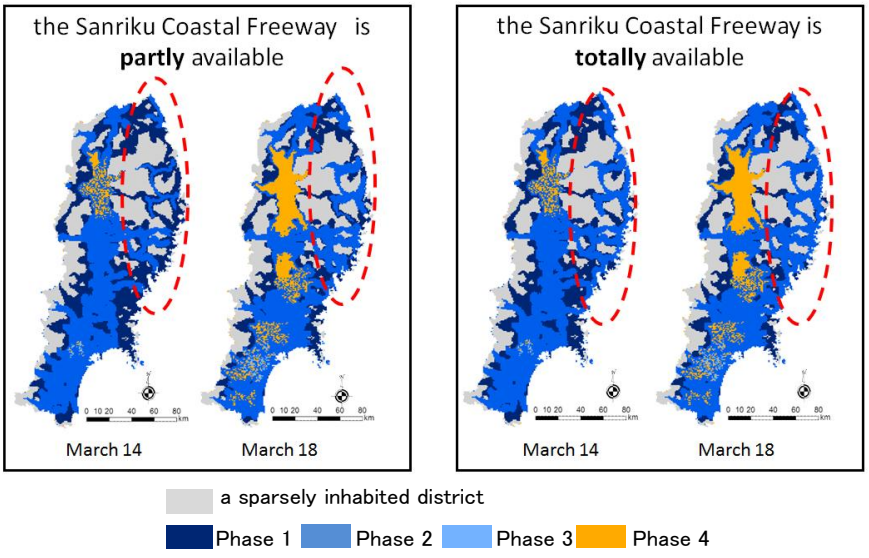

Fig. 10. Transition of QOL phases. (Left) Partly available, (Right) Totally available

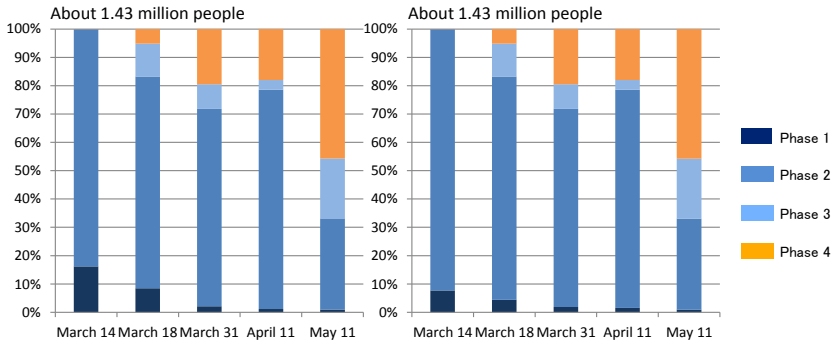

Fig. 14. Transition in the number of refugees belonging to each QOL phase in the coastal area. (Left) Partly available, (Right) Totally available

6. Conclusions

6.1. Consideration

This study aims to establish a system to evaluate the post-disaster living environment for refugees in each small district with regard to refugees' QOL. We apply this system to the Tohoku coastal area that suffered severe damage from The Great East Japan Earthquake on March 11th, 2011. The findings are as follows:

- Recovery of QOL in the inland area is earlier than in the coastal area due to serious infrastructure destruction by the tsunami in the coastal area.
- In the coastal area, recovery of QOL in the districts that have a rich road network toward the inland area is early.
- In the case in which the whole Sanriku Coastal Freeway is available, the QOL recovered earlier in the coastal area. It was shown that improvement in the redundancy of a road network contributes to the maintenance and improvement in QOL immediately after the disaster.
- Though the road network along the coast may be strengthened, recovery of QOL like inland is not seen. It became clear that the damage to lifelines or facilities in the coastal area has long-term influence on the decline of QOL.
- It was found that construction of a road network and arranging institutions for use in time of disaster are needed.

6.2. Future works

Future works are as follows:

- There is a need to consider the QOL elements that are not taken into account in this study, and to consider quantities of food and water to determine whether enough is available for the whole population in each district.
- A further follow up of this study will be to simulate a future disaster. Evaluation of post-disaster refugees' living standards based on more comprehensive QOL indicators will contribute to improving future disaster management.

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