Analysis of the Reconstruction Process After the Great East Japan Earthquake Using GPS Data

Ryosuke Toida, Yoshihide Sekimoto, Teerayut Horanont, Hiroshi Kanasugi and Ryosuke Shibsaki

University of Tokyo; corresponding author: rtoida@csis.u-tokyo.ac.jp

Abstract

On March 11, 2011, the Tohoku Earthquake (Mw 9.0) struck Japan, causing serious human and material damage mainly in three Tohoku prefectures: Iwate, Miyagi, and Fukushima. The stricken areas are now in the midst of reconstruction; thus, it is very important to comprehend and evaluate this process correctly on a time axis to image the most suitable reconstruction process for the area and to propose the most effective measures for disaster prevention. Thus, in this study, we used large-scale, long-term GPS data from a mobile phone and probe-car data to evaluate the reconstruction process correctly and quantitatively. Specifically, five indices for the activities of people in the area and an index for the restoration status of roads were created by analyzing the data. Moreover, factors having an impact on reconstruction progress are clarified through a classification and comparison of damage types.

1.Introduction

On March 11, 2011, the Tohoku earthquake (Mw 9.0), the largest in Japan's recorded history, caused serious human and material damages. As of November 28, 2012, human damage was 18,618 deaths and approximately 40,000 missing people, and house damage consisted of the complete destruction of 129,642 houses and damage to 266,512. The Iwate, Miyagi, and Fukushima prefectures in the Tohoku region suffered the most serious damage, consisting of the destruction of houses, roads, and other structures caused by seismic motion, nuclear accidents, and even harmful rumors. The disaster stricken areas are in the midst of reconstruction now; thus, it is very important to comprehend and evaluate this process correctly on a time axis in order to image the most suitable reconstruction process for the area and propose the most effective measures of disaster prevention. Although we can gain some knowledge from media reports on the state of reconstruction, few researchers have tried to analyze this process using quantitative data.

A previous study was carried out by the National Institute for Research Advancement (NIRA). In this report, changes were made in recovery and reconstruction after the earthquake was analyzed in 37 municipalities hit by the tsunami, using two indices: one expressing the status of the recovery of the basic infrastructure, and the other expressing the activities of the people, created by a combination of related statistical data. Analysis using such statistical data has some problems, however: data acquisition is costly, and detailed analysis is difficult because essential data is not available, the data is limited to prefectural data, or the census frequency is low. On the other hand, one method uses the Global Positioning System (GPS) to compile data on people's activities. In recent years, its utility value has increased, and it is now used in various research fields. Research using GPS data includes an analysis of human mobility in the Tohoku earthquake in the Tokyo metropolitan area by Sekimoto et al. (2012) and an analysis of actual sightseeing conditions in Ishikawa Prefecture by Ubukata and Sekimoto (2012); both studies look at the possibility using large-scale and long-term GPS data for analysis. Moreover, ITS Japan unveiled traffic information in the stricken area based on probe-car information collected from several auto manufacturers, such as Honda, Nissan, and Toyota, after the earthquake. Since data like this were extremely helpful for moving, rescue operations, and support activities in the stricken areas, its importance has been recognized.

Thus in this study, we attempt to analyze large-scale, long-term GPS data using mobile phones and probe-car data so as to evaluate the earthquake disaster reconstruction process quantitatively. The "hard"—i.e., the infrastructure—side of reconstruction (recovery of electric power, gas lines, roads, railways, and other structures) is often discussed, but the activities of the people living in the area—i.e., the soft side—are as important as rebuilding the environment. Thus, the process is evaluated from the standpoints of both the hard and soft sides through an examination of reconstructing people's activities as well as the restoration of the infrastructure.

First, some indices were created by analyzing the activities of people before and after the earthquake with mobile phone GPS data, and the activity of each municipality was calculated. Next, the restoration rate of roads in each municipality was calculated from the number of navigable roads by analyzing car traffic conditions using probe-car data. Moreover, factors that have an impact on reconstruction progress were deduced by classification and comparison of damage types.

2. Methodology

2.1. Data used

a) Mobile-phone GPS data

In this study, "Congestion Statistics," a collection of statistical data provided by ZENRIN Data Com Company, was used. "Congestion Statistics" is generally processed so that individuals cannot be determined for confidentiality reasons. However, non-totaling data, not including attribute information (sex, age, etc.), were used with the cooperation of ZENRIN. Original GPS data had been acquired by "auto GPS," which was provided by NTT DOCOMO. "Auto GPS" may be explained as a function that periodically determines the position of the customer and automatically provides the service provider with the information in the background, having been set up to do so in advance. Thus, it differs from the old positional measurement taken when a user operates the GPS function on a phone. With NTT DOCOMO service, positioning is performed at intervals of 5 minutes, or according to the shortest interval obtained by customer consent, and then the location information is always acquired and transmitted except for when the customer is out of range. There are two kinds of positional measurement: GPS positioning using electrical waves from a satellite and that which uses information at a base station, and the latter may be in error by 300 m or more. Therefore, the error level is classified into three grades: level 1 (300 m or more), level 2 (less than 300 m), and level 3 (less than 50 m). Persons eligible for inclusion in "Congestion Statistics" constitute about 0.5% of the population because the number of current users of auto GPS is considered to be 700,000 to 800,000 people. These data include ID (identified as individual), date, latitude, longitude, altitude, and error level. The period of the data is from August 1, 2010 to July 31, 2011.

b) Probe-car data

The data were provided by the National Institute for Land and Infrastructure Management (NILIM), and it is based on data acquired from guidance obtained from a navigation application: "Zenryoku Annai" and "Itsumo Navi." The data include the secondary mesh code, the inflow node of the DRM (Digital Road Map), the outflow node of the DRM, date of entry in a link, trip time, data source, and latitude and longitude of the inflow node. Here, a node is a crossing or a node for expressing a road network, and a link is a road section between nodes.

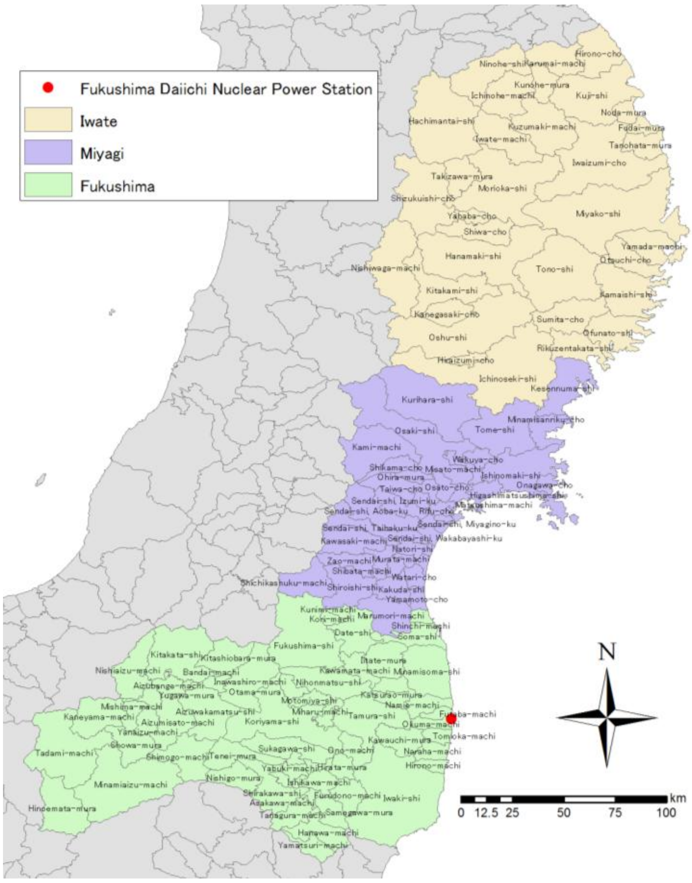


Figure 1. Position of the 3 Tohoku prefectures

2.2. Target area

The 3 Tohoku prefectures, Iwate, Miyagi, and Fukushima, are analyzed by municipality, of which Iwate has 33, Miyagi has 39, and Fukushima has 59. The position of each prefecture and municipality is shown in Figure 1. These prefectures face the Pacific Ocean, and the alignment in order from the north is Iwate, Miyagi, and Fukushima. In addition, Fukushima Daiichi Nuclear Power Station, where the accident occurred, is shown with a red mark.

2.3. Method

Table 1. The number of IDs

	Iwate	Miyagi	Fukushima
ID having stay record	11,644	21,766	16,811
ID having “home” before the earthquake	9,948	18,487	14,471
ID having “office” before the earthquake	10,720	19,818	15,606

a) Mobile-phone GPS data

In this study, we analyzed annual data from August 1, 2010 to July 31, 2011. First, IDs having at least one stay record in Iwate, Miyagi, and Fukushima were extracted from all the data and only IDs from before the earthquake (March 10, 2011) were used for this stage of the analysis. Next, the positions of “home” and “office” were estimated for each ID and the municipalities for these locations were determined. “Home” was considered to be the municipality containing the highest number of stay records from 12:00 midnight to 6 a.m., and “office” the municipality having the most stay records from 10 a.m. to 4 p.m. Thus, “home” is the place the person lives, and “office” the place to which the individual consistently goes, but it could be office or school. The frequencies of “home” and “office” were each determined before the earthquake (from August 1, 2010 to March 10, 2011), and for every week after the earthquake (from March 11, 2011 to July 31, 2011). Table 1 shows the number of IDs having a stay record in each of the 3 prefectures and those having a “home” and “office” record before the earthquake. A comparison of the number of IDs having stay records shows that Miyagi has the most and Iwate has the least. There were also more “office” than “home” IDs in each of the 3 prefectures.

The 5 indices based on these statistics consist of numbers of the following: resident, constant visitor, temporary visitor, migration length, and range of movement. The indices for resident, constant visitor, and temporary visitor show activity in the municipalities themselves, and the meaning of each index was established as follows: people living in the municipality (calculated from the number of people having a “home” in the municipality), people going to the municipality for office or school (calculated from the number of people having an “office” in the municipality), people visiting the municipality for sightseeing or shopping. Even if there are stay records in the municipality, if the ID is not a resident or constant visitor (i.e., not “home” or “office”), it is considered to be a temporary visitor. Therefore, temporary visits include very short stays, such as passage through by train or car, as well as visitors having a particular purpose. On the other hand, the indices of migration length and range of movement show the activity of the people who live in the municipality, and the meaning of each index is as follows: migration length is how far they moved in a day (calculated from the sum total of distance connecting points for which there is a GPS record every day), and the range of movement is how far they visited from their house (calculated from the distance at the furthest point from “home”).

b) Probe-car data

Roads that were not passable were seen in the 3 prefectures after the earthquake because of blockades, mainly because of damage to the road surface and debris or because of traffic regulations for precedence given to emergency vehicles. The restoration ratio of roads could be an index showing earthquake disaster reconstruction because it becomes easier to carry relief goods, and people's normal movements will also increase with restoration of the roads.

In this study, we used annual probe-car data from March 1, 2011 to February 29, 2012. First, the municipality in which each link is included is determined from the position coordinate of the nodes, and the number of all links included in each of the municipalities was calculated. All links are roads for which there is a passing history even once from March 1, 2011 to February 29, 2012. Therefore, strictly speaking, it cannot be said that the number of actual roads is shown. The restoration ratio of roads is defined as the percentage of links that have a passing history from the earthquake occurrence to another point in time in all links, and the number of available passable roads was analyzed.

2.4. Classification of municipalities by damage types

We grouped the municipalities into the following 4 categories (a – d) by damage types, and analyzed them. One category has 5 municipalities in which the damage is the worst.

a) Area where observed earthquake record was greater

Using observed earthquake records from strong-motion seismograph networks (K-NET, KiK-net), we chose municipalities in which the earthquake measured an intensity of 6+ and which are inland from the coast. This data has been made public by the National Research Institute for Earth Science and Disaster Prevention (NIED). The 5 municipalities chosen are Sendai-shi Miyagino-ku, Miyagi; Kurihara-shi, Miyagi; Tamura-shi, Fukushima; Nishigo-mura, Nishishirakawa-gun, Fukushima; and Miharu-machi, Tamura-gun, Fukushima. In these municipalities, intensity 7, as measured in Kurihara-shi, Miyagi, is the highest, but it was reported that the number of damaged houses was extremely small for the intensity.

b) Area where percentage of surface area inundated by the tsunami was high

The inundation report from the tsunami is from the Geospatial Information Authority of Japan (GSI) and the 5 chosen municipalities are Sendai-shi Wakabayashi-ku, Miyagi; Iwanuma-shi, Miyagi; Watari-machi, Watari-gun, Miyagi; Yamamoto-machi, Watari-gun, Miyagi; and Shichigahama-machi, Miyagi-gun, Miyagi. In this report, the range of inundation was determined by finding traces of flooding (in a paddy or colony, debris, etc.) in aerial and satellite images. Note that human damage is not always serious because the percentage of inundated surface area is high.

c) Area where human damage was serious

We used prompt damage reports which each of the 3 Tohoku prefectures has made available, and the 5 municipalities having the most dead and missing people are Rikuzentakata-shi, Iwate; Otuchi-cho, Kamihei-gun, Iwate; Ishinomaki-shi, Miyagi; and Kesennuma-shi, Miyagi; Higashimatsushima-shi, Miyagi. It can be said that these municipalities suffered serious human damage because over 1000 people are dead or missing. Among them, Ishinomaki-shi especially suffered serious human damage with 4,000 dead or missing people, and the number of fully or partially destroyed houses is approximately 23,000.

d) Area near the nuclear power plant

The chosen municipalities near the accident at the Fukushima Daiichi Nuclear Power Station are Naraha-machi, Futaba-gun, Fukushima; Tomioka-machi, Futaba-gun, Fukushima; Ookuma-machi, Futaba-gun, Fukushima; Futaba-machi, Futaba-gun, Fukushima; Namie-machi, Futaba-gun, Fukushima. Incidentally, Fukushima Daiichi Nuclear Power Station is between Ookuma-machi and Futaba-machi.

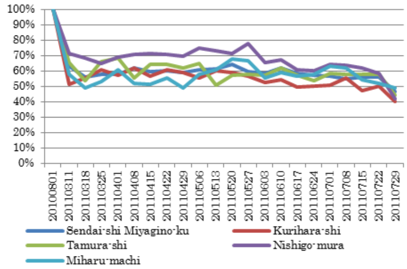
3. Results

In this chapter, the result is shown for the municipalities grouped by damage types in section 2. The vertical axis of the graph is for each index and the horizontal for the time. In order to make it easy to compare the changes after the earthquake to the situation before, numerical values from before are assumed to be 100%, and changes in values after that are shown in a time series. In the result shown in the following section, the data from August 1, 2010, to March 10, 2011, were totaled as a whole, and the data from March 11, 2011, to July 31, 2011, were totaled for each week.

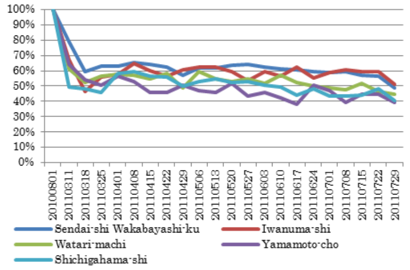
3.1. Residents

The result for each municipality is shown in Figure 2. We can see that the indices in every municipality drop sharply just after the earthquake but recover gradually after that. Next, the result of each area was considered in detail. Figure 2-1 shows the result for the area where the observed earthquake intensity was higher; the index drops to nearly 50%, at most, after the earthquake and has been generally flat with hardly any recovery. This tendency can be seen in Figure 2-2. In this area, the percentage of inundated surface area was high, but the number of dead and missing people was comparatively small. This result may be because the damage type in 2-2 is very similar to that in 2-1.

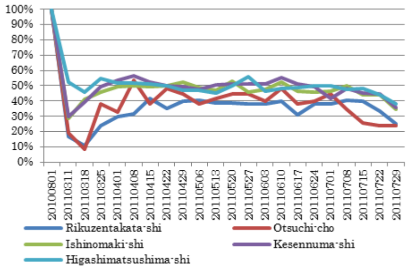
On the other hand, results from the area where human damage was serious are shown in Figure 2-3, and the range of the drop is very large compared with Figures 2-1 and -2. In particular, the tendency is shown strongly in Rikuzentakata-shi and Ootsuchi-cho, where it temporarily becomes about 10% of the level before the earthquake. This result may stem from the percentage of dead and missing people, which is very high (more than 8%) in these municipalities compared to the others. That is, the number of people who were forced to evacuate temporarily or permanently was in large areas where there was large-scale human and material damage, and the evacuation site was often outside of the area. The result for the area near the nuclear power plant is shown in Figure 2-4. The range of drop just after earthquake is the largest and it did not recover afterward. This is because there was an evacuation order and a request for voluntary evacuation after the accident at the Fukushima Daiichi Nuclear Power Station. That is, few people were able to go their homes, at least from the earthquake time to July 31, 2011.



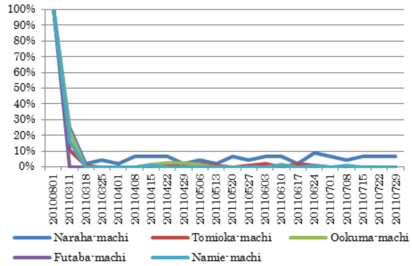
(1) Area where observed earthquake record was greater



(2) Area where percentage of inundated surface from the tsunami was high



(3) Area where human damage was serious

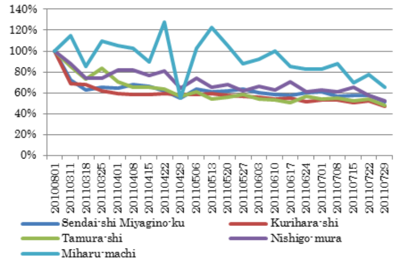


(4) Area near the nuclear power plant

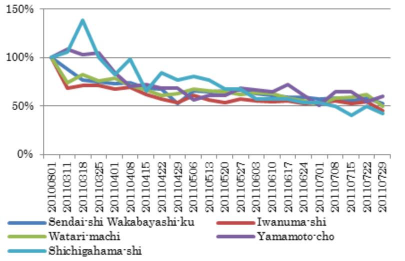
Figure 2. Index of residents

3.2. Constant visitors

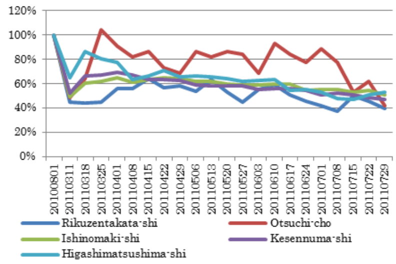
The results for constant visitors are shown in Figure 3. Compared with that for residents, the range of the drop is small and gradual. Because this index would normally drop after an earthquake, it seems that an unanticipated motion, such as a rise, might stem from such occurrences as volunteer work or mass transport for victims.



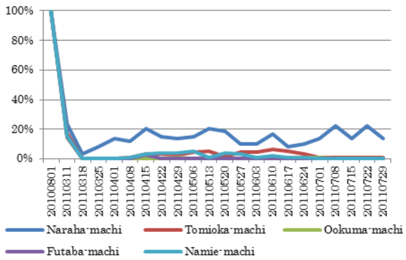
(1) Area where observed earthquake record was greater



(2) Area where percentage of inundated surface from the tsunami was high



(3) Area where human damage was serious

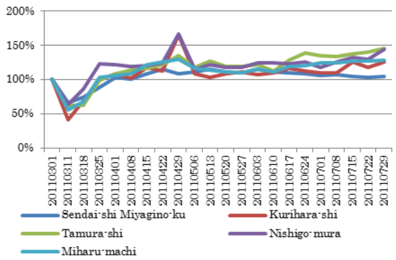


(4) Area near the nuclear power plant

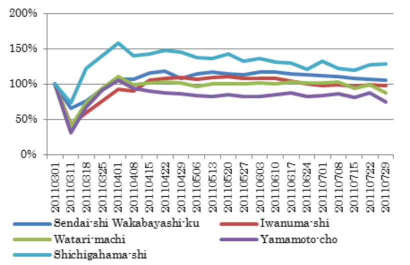
Figure 3. Index of constant visitors

Figures 3-1 and 3-2 show tendencies similar to those of residents. However, the index rises temporarily over the level existing before the earthquake in Miharu-machi, Yamamoto-machi, and Shichigahama-machi. This would seem to indicate the presence of many volunteers who visited constantly to remove damaged houses, debris, etc. That of residents, however, does not rise in this period, as they may be based in neighboring municipalities. In Miharu-machi, the number drops sharply in the long vacation, called the Golden Week, from April 29, 2011, to May 5, 2011. This shows that constant visitors who usually went to this town went to another area in this period. The results from the area where human damage was the most serious are shown in Figure 3-3. The number drops sharply in Rikuzentakata-shi and Ootsuchi-cho, both of which had serious damage, as well as that of residents, scarcely recovering afterward in Rikuzentakata-shi. Habitual volunteering from neighboring areas is very low because neighboring areas were also damaged by the tsunami. Figure 3-4 shows the same tendency for visitors as for residents, but the index changes between 10% and 20% in Naraha-machi, which is the farthest south and, thus, the farthest of the 5 municipalities from the nuclear power plant. The results show a certain number of constant visitors, possibly arising from people returning for special reasons, such as arrangement of their houses and care of domestic animals and fields, only during the daytime.

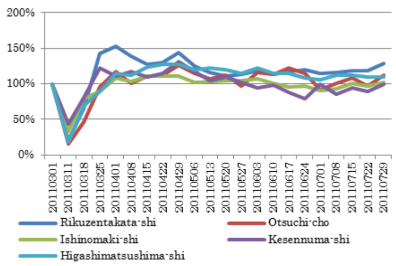
3.3. Temporary visitors



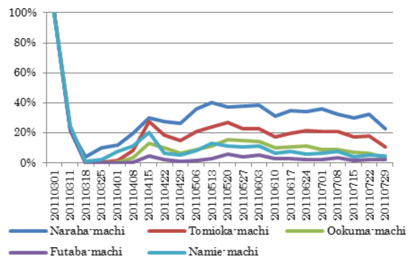
(1) Area where observed earthquake record was greater



(2) Area where percentage of inundated surface from the tsunami was high



(3) Area where human damage was serious



(4) Area near the nuclear power plant

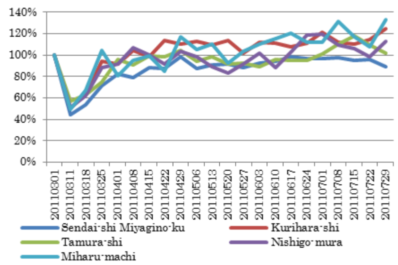
Figure 4. Index of temporary visitors

The results are shown in Figure 4. Compared with previous indices, the range of the drop just after the earthquake is large, but it recovers to the level it was before the earthquake or more except for the area near the nuclear power plant. The reason is that residents and constant visitors stay longer than a short period of time, whereas temporary visitor stays include those that are very short. This result shows that the majority of people kept to their homes for a while immediately after the earthquake but began to move more actively soon after that. Moreover, it may be that many single isolated volunteer participants from the Kanto area were included among these people because the results show that the number of temporary visitors increases during the long vacation from April 29, 2011, to May 5, 2011. However, we need to examine why this tendency cannot be seen in Figure 4-2. Compared with Figures 4-1 and -2, it recovers rapidly, although the range of the drop is large just after the earthquake in Figure 4-3.

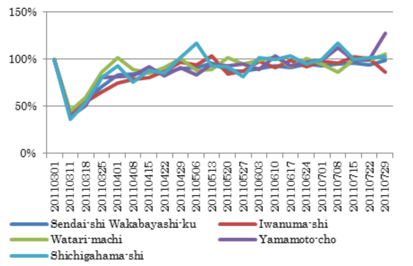
This may be the result of people who flowed in from outside the concentrated damage area.

3.4. Migration length

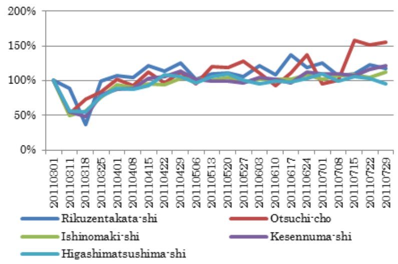
Next, the results for migration length, which show the activity of people living in the municipality, are shown in Figure 5. The index drops to about 50% except for areas near the nuclear power plant, as well as other indices, but converges at 100% soon after that. This shows that the value of migration length does not depend much on the difference in damage types. The value for Figure 5-4 is uneven, possibly because the residents are only a few people and the number of samples is extremely small, despite the migration length being defined as that of residents in the municipality.



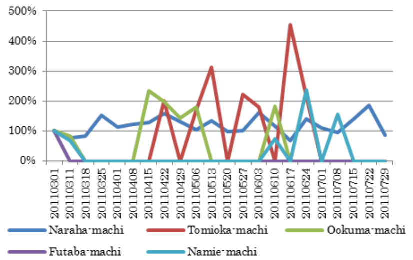
(1) Area where observed earthquake record was greater



(2) Area where percentage of inundated surface from the tsunami was high



(3) Area where human damage was serious

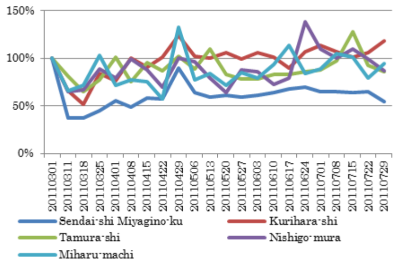


(4) Area near the nuclear power plant

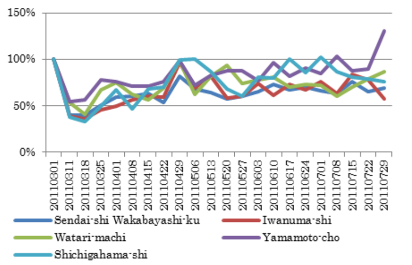
Figure 5. Index of migration length

3.5. Range of movement

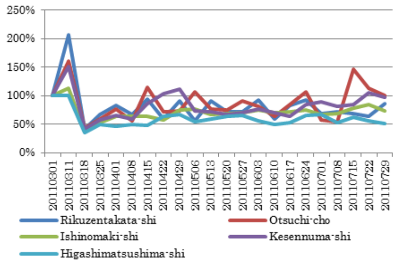
The results for the range of movement are shown in Figure 6. Compared with migration length, this index drops sharply as well just after the earthquake but does not go back to the pre-earthquake level soon after that. Moreover, there are clear differences between categories, so the damage type is a factor. Figures 6-1 and -2 show that the range of movement drops just after the earthquake, probably because people went out less than usual from uneasiness and self-restraint. However, it rises in Figure 6-3. The tendency is especially noticeable in Rikuzentakta-shi and Ootsuchi-cho, which suffered serious human damage from the tsunami. The reason may be that people living in an area sustaining little damage evacuated to nearby neighborhoods and the number of evacuees was small, but people in areas with a lot of damage evacuated to faraway places, such as homes of relatives or friends. The results in Figure 6-4 are probably influenced by the fact that the number of samples is small and by the migration length.



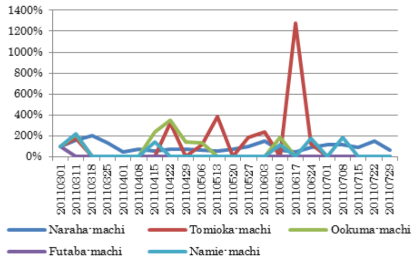
(1) Area where observed earthquake record was greater



(2) Area where percentage of inundated surface from the tsunami was high



(3) Area where human damage was serious



(4) Area near the nuclear power plant

Figure 6. Index of range of movement

3.6. Restoration of road

Next, the restoration condition of the roads in each category, obtained from probe-car data, is shown in Figure 7 and 8. First, we can see that the restoration is very slow near the nuclear power plant and that only half of all the roads had been restored by February 2012, one year after the earthquake. The reason is not so much owing to road damage as to the nuclear accident, and entering the municipality was impossible because of traffic regulations or evacuation orders.

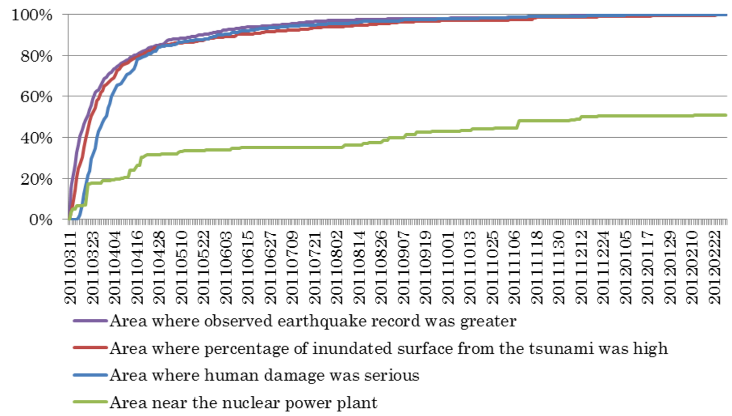
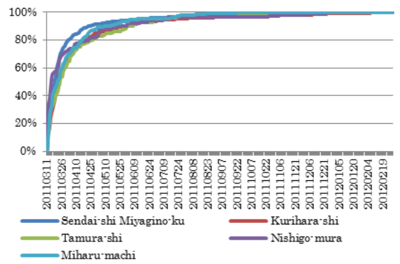
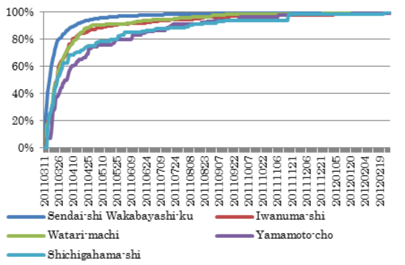


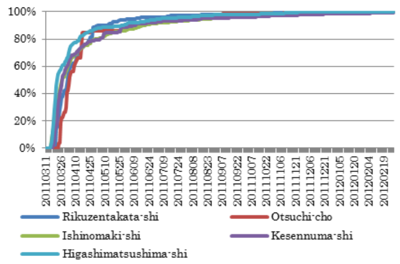
Figure 7. Road restoration conditions



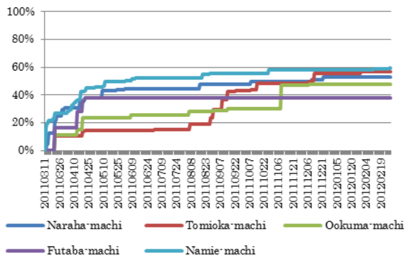
(1) Area where observed earthquake record was greater



(2) Area where percentage of inundated surface from the tsunami was high



(3) Area where human damage was serious



(4) Area near the nuclear power plant

Figure 8. Road restoration conditions

In the other municipalities, there are differences in the condition of restoration just after the earthquake, but they recover in the same way after May 2011: there is a great difference between areas where the observed earthquake record was greater and areas where human damage was serious. The serious human damage was caused mainly by the tsunami, demonstrating that tsunami damage was much greater by way of comparison with damage from seismic motion only.

3.7. Discussion

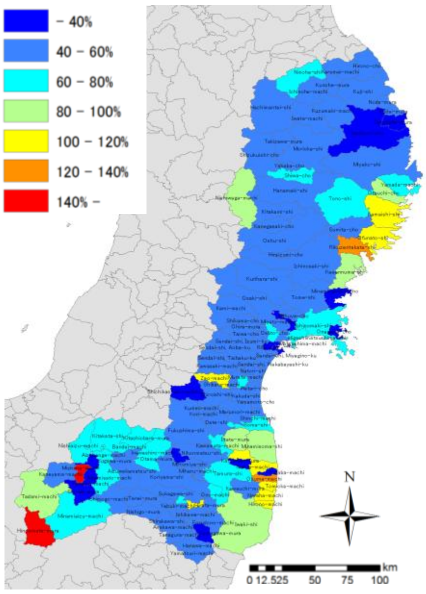
Here, we examine the mobile-phone GPS data. First, in terms of each category, we have shown that all indices drop just after the earthquake in the same way, but a difference according to indices or damage types can be seen in the moves after that. In terms of category comparison, (1), area where the observed earthquake record was greater, and (2), area where percentage of surface inundated by the tsunami was high, were similar in terms of index motion, but (3), area where human damage was serious, is considerably different from the other two. The difference in the amount of human damage size is believed to be the reason. Even if (1) and (2) are high, the human damage is not always serious. On the other hand, (3) shows that many people were killed by the tsunami, and this difference in human damage brought about these different results. Compared with residents and constant visitors, there is no difference between those categories and that of temporary visitor except for just after the earthquake and this is thought to result from a fixed number of volunteers from outside. The amount of inflow—volunteers, donations, and goods—from the outside depends heavily on the degree of exposure to the situation in the media. Further research, therefore, should take into account the media coverage and the inflow from outside the communities as main points of investigation. As for (4), the area nears the nuclear power plant, it is a particular case, and there is scarcely any recovery, even some time after the earthquake. Compared with the other areas, this one includes psychological problems, which also complicate the situation. Thus, recovery to the original level before the earthquake will take a long time.

Next, each index is discussed. The number of residents drops more sharply and recovers more slowly than the others, but because it refers to the number of people living in the area, a decline in the area after the earthquake would be expected and is accurate. Constant and temporary visitors include many people flowing in from the outside, so they do not, strictly speaking, directly demonstrate the earthquake reconstruction. However, considering that the inflow likely contributes to the reconstruction of the area, we may infer that these indices indirectly show reconstruction progress. On the other hand, migration length and range of movement show the activity of people living in the area, and confusion after the earthquake can be discerned from these indices. Movement from activity had not recovered as of July 2011, unlike migration length. Therefore, it seems that recovery of this index would mean that the normal life of the people would be near its original level before the earthquake, so range of movement can be a significant index demonstrating ongoing reconstruction.

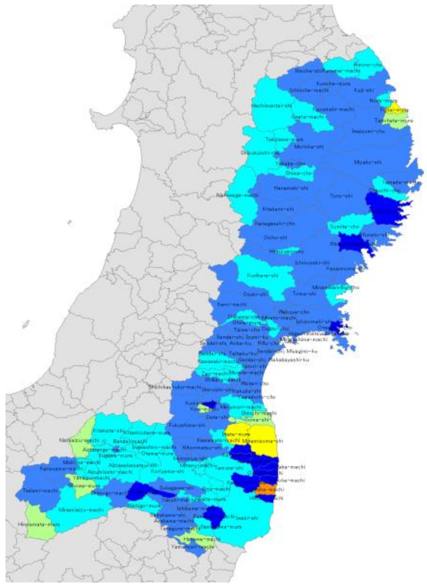
Last, people’s activity, the sum of 5 indices, after the earthquake was made visible on map. Changes of activity in four periods are shown in Figure 9 (numerical values before the earthquake are assumed to be 100%). Figure 9-1 shows that people’s activity is very high compared with neighboring areas just after the earthquake, from 11, March, 2011 to 17, March, 2011, in coastal area in Iwate and near the Fukushima Daiichi Nuclear Power Station. However it is rather lower in next week, from 18, March, 2011 to 24, March, 2011. This is result that people’s activity rises temporarily for confusion just after the earthquake. Moreover, changes after that to July, 2011 show that reconstruction is going smoothly at least in terms of people’s activity except for area near the nuclear power plant.

4. Conclusions

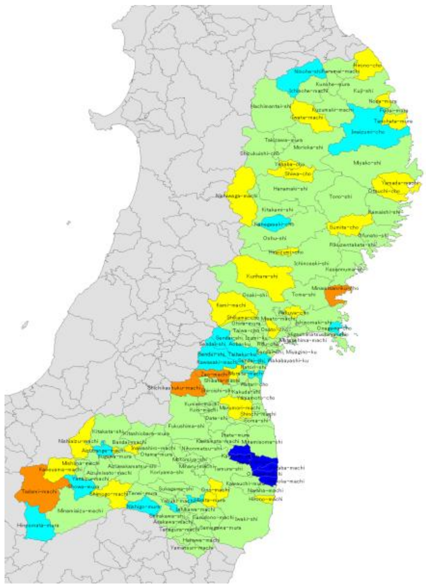
In this study, the municipalities belonging to the 3 Tohoku prefectures that suffered from the earthquake were classified by main damage types, and the progress of reconstruction from the earthquake disaster was analyzed using mobile-phone GPS data and probe-car data. First, people’s activity before and after the earthquake was garnered from mobile-phone GPS data, and the activity of each municipality was calculated by means of certain indices. Specifically, the home and office of each ID was estimated, and the indices of resident, constant visitor, temporary visitor, migration length, and range of movement were calculated based on that. Next, the traffic conditions were analyzed using probe-car data, and the restoration rate of roads was calculated from the percentage of passable roads among all roads.



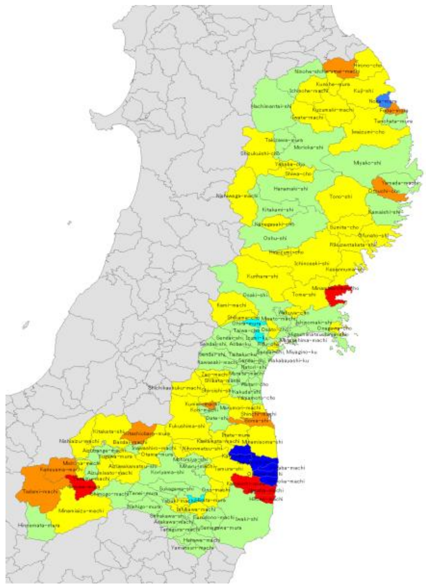
(1) From 11, March, 2011 to 17



(2) From 18, March, 2011 to 24



(3) From 20, May, 2011 to 26



(4) From 22, July, 2011 to 28

Figure 9. Visualization of people's activity

As a result, we showed that although every index drops just after the earthquake, the changes after that differ, depending on the index or category. A comparison of the categories shows that areas where the observed earthquake record was greater and areas where the percentage of inundated surface area from the tsunami was high have similar tendencies. However, areas where human damage was serious differ considerably from the above-mentioned areas, and it has been demonstrated that reconstruction progress is delayed in this area. Moreover, areas near the nuclear power plant constitute a particular case and cannot be compared with the other places. For example, psychological problems must be considered in those areas, so recovery to the original level before the earthquake will take a long time. In comparison with the other indices, we consider that the resident index, which shows the activity in the areas themselves, is accurate in demonstrating the decline of a city from the earthquake. In terms of constant and temporary visitors, people flowing in from the outside after the earthquake can be captured from the data, but more people whose purpose was not office, school, sightseeing, or shopping have been measured as a result. Thus, we believe that these indices do not show reconstruction directly but may show it indirectly. As for migration length and range of movement, which are the indices showing the activity of people living in the area, migration length cannot serve as a valid index to show reconstruction, but range of movement can because it shows behavior after the earthquake well. Finally, for the results on the restoration of roads demonstrate that restoration has been delayed in areas where human damage was serious, agreeing with results from the other indices in this regard.

Concerning future research, whereas municipalities were classified by damage types in this study, we would like to try other classifications, such as the amount of human inflow, contributions, goods, and degree of exposure to the media. Doing so would clarify the significant factors affecting the reconstruction. Moreover, we would like to make sure the validity compares with actual statistical data.

Acknowledgement

Data used in this study were provided by Zenrin Data Com and the National Institute for Land and Infrastructure Management (NILIM).

References

National Police Agency: Emergency Disaster Countermeasures Headquarters, 2012, Damage Situation and Police Countermeasures In the 2011 Great East

Japan Earthquake, http://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf (accessed 28 November, 2012)

Cabinet Office, Government of Japan: Team in Charge of Assisting the Lives of Disaster Victims, 2011, Evacuees at Shelters (All Prefectures), http://www.cao.go.jp/shien/en/2-count/annex1-4.pdf (accessed 28 November, 2012)

Japan Meteorological Agency, 2011, Earthquake and Tsunami Early Warning in Time of Disaster, http://www.jma.go.jp/jma/kishou/books/saigaiji/saigaiji_201101/saigaiji_201101.pdf (accessed 28 November, 2012)

National Institute for Research Advancement, 2011, Indexes for Recovery and Reconstruction following the Great East Japan Earthquake, http://www.nira.or.jp/pdf/1102english_report.pdf (accessed 28 November, 2012)

Sekimoto, Y., Nakamura, T., Masuda, Y. and Kanasugi, H., 2012, Human Mobility Analysis in the Great East Japan Earthquake in Tokyo Metropolitan Area Using Large-Scale GPS Data, Journal of Japan Society of Civil Engineers (JSCE), 45(249).

Ubukata, Y., Sekimoto, Y., 2012, Analysis of the Actual Sightseeing Conditions Using GPS Data, Journal of Japan Society of Civil Engineers (JSCE), 45(370).

ITS Japan, Probe Helps Traffic Information in Disaster Area, 2011, http://www.its-jp.org/english/its_asia/553/ (accessed 28 November, 2012)

NTT DOCOMO, INC., The positioning method, http://www.nttdocomo.co.jp/service/safety/search/usage/gps/ (accessed 28 November, 2012)

National Research Institute for Earth Science and Disaster Prevention (NIED), Strong-Motion Seismograph Networks (K-NET, KiK-net), http://www.kyoshin.bosai.go.jp/kyoshin/ (accessed 28 November, 2012)

Geospatial Information Authority of Japan, About Area of the Tsunami Flood Zone (5th report), 2011, http://www.gsi.go.jp/common/000059939.pdf (accessed 28 November, 2012)

Iwate Prefecture, The Table of Human and Material Damages in the Great East Japan Earthquake, 2012, http://www.pref.iwate.jp/~bousai/taioujoukyou/201211091700jintekihigai.pdf (accessed 28 November, 2012)

Miyagi Prefecture, Damage Information in the Great East Japan Earthquake, 2012, http://www.pref.miyagi.jp/uploaded/attachment/115079.pdf (accessed 28 November, 2012)

Fukushima Prefecture, The Early Damage Report in the Great East Japan Earthquake (794th report), 2012. (accessed 28 November, 2012)