

# A COMPARATIVE STUDY ON HUMAN IMPACTS CAUSED BY THE 2011 GREAT EAST JAPAN EARTHQUAKE AND DISASTER MITIGATION

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**ABSTRACT:** This study investigates into the relationships of the various factors in the loss of human lives caused by the 2011 Great East Japan Earthquake in March 11, 2011. A comparative study illustrates the difference between the casualty in Banda Aceh, Indonesia during the 2004 Indian Ocean Tsunami and several typical affected areas in Japan. In order to elucidate the human impacts, 80,000 witnesses from Tohoku to Kanto area were analyzed. Therefore, integrated strategies for the reduction of the casualty in large-scale natural disasters in the future are proposed in this study.

**Key Words:** Great East Japan earthquake, disaster mitigation, behavioral perspective, comparative study

## INTRODUCTION

The gigantic earthquake off the Pacific coast of Tohoku, Japan (38.1035°N, 142.861°E, M 9.0 at 14:46:18 JST according to Japan Meteorological Agency) on March 11, 2011 generated a huge tsunami, which caused catastrophic damages in a vast areas of Tohoku and Kanto. The number of human lives reached 15,845 fatalities and 3,380 missing according to an announcement made by the National Police Agency (January 23<sup>rd</sup>, 2012)<sup>1</sup>. The tsunami inundated a large area, and destroyed a huge number of houses, buildings and infrastructures, such as railways, roads, bridges and quay walls. The tsunami also severely damaged various lifeline systems, water, sewer, electricity and telecommunication. The accident at the Fukushima No. 1 nuclear power plant, which was caused by the earthquake and the tsunami, created the most serious damage and continues to be in a critical situation. As many as 50,000 residents within 30 km (19 miles) of the plant have been forced to move far from the contaminated area. Furthermore, the in the refuge areas is supposed to continue for an extended time. However, we have to find the future directions to create a safer and more secure society against future earthquakes and tsunamis based on the lessons from this disaster.

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<sup>1</sup> The National Police Agency (<http://www.npa.go.jp/archive/keibi/biki/higaijokyo.pdf>)

Table 1 Summary of damages in the 2011 Great East Japan Earthquake

Earthquake	Magnitude	Area	Inundation area (km <sup>2</sup> )	Casualty (Death/Missing)	Structure Damages
The 2011 Great East Japan Earthquake	9.0	whole Japan	561	19,800	113,300
		Iwate Pref.	58	6,315	20,209
		Miyagi Pref.	327	11,618	75,391
		Fukushima Pref.	112	1,843	17,740
Meiji-Sanriku (Estimated Damage)	8.6	whole Japan	270	2,700	9,400
		Iwate pre.	50	2,100	6,400
		Miyagi pre.	60	360	2,000
		Fukushima pre.	20	60	300

(Source) [Tohoku district Pacific offing earthquake]

Magnitude: Japanese Meteorological Agency "the 2011 off the Pacific coast of Tohoku Earthquake (15th report)" (2011.3.13)

Inundation area: Geographical Information Authority of Japan "Inundated areas caused by the tsunami (5<sup>th</sup> report)" (2011.4.18)

Casualty/Structure damages: National Police Agency "Damage situation and Police Countermeasures associated with 2011 Tohoku district-off the Pacific Ocean Earthquake" (September 26, 2011)

[Meiji-Sanriku (Estimated Damage)]

Magnitude: Trench-type earthquakes around Japan Trench-Kuril Trench (H18.1.25), p67, (calculated value from a fault model)

Inundation area: the assumed value for assumption damage from the Meiji-Sanriku type earthquake with dikes

Casualty/Structure damages: Specialized investigation committee for Trench-type earthquakes around Japan Trench-Kuril Trench (January 25, 2006), p 55, p 57

## HUMAN IMPACTS OF THE DISASTER

The escalation of natural disasters in 2011 brought many concerns with Japan's earthquake which was an unprecedented event. However, the loss of humans as a result of earthquakes is avoidable and preventable. A mitigation of deaths and injuries is of a primary concern to all disaster prevention efforts<sup>2</sup>. The focus of the present study is on the death tolls of human lives because of the huge number of death in wide inundated areas (56 km<sup>2</sup>, 6 prefectures, 62 cities)<sup>3</sup> is still in an ongoing classification.

### Cause of death

The earthquake triggered powerful tsunami waves that caused extensive and severe damages in Japan. Of the 13,135 fatalities recovered by 11 April 2011, 92.5% died by drowning and others were caused by non-tsunami reasons, like being crushed or injured, and by fire<sup>4</sup>.

Table 2 Cause of death

Cause of Death	Number	Percentage
Drowning	12,143	92.4%
Crushing, Injury	578	4.4%
Fire	148	1.1%
Unknown	266	2.0%
Total	13,135	100%

<sup>2</sup> Earthquake Casualties Research and Public Education, M. Petal

<sup>3</sup> Geospatial Information Authority of Japan (<http://www.gsi.go.jp/common/000059939.pdf>)

<sup>4</sup> Asahi newspaper (<http://www.asahi.com/special/10005/TKY201104190477.html>)

Across twelve prefectures, the earthquake and tsunami left enormous damages to wide area.

Table 3 Damages breakdown by twelve prefectures<sup>5</sup>

Prefecture	Death	Missing	Complete destruction	City (Prefecture)	Rate of Casualty	Casualty Number	Population of 2010
Hokkaido	1	0	0	Kamaishi (Iwate)	2.78%	1,091	39,508
Aomori	3	1	307	Rikuzentakada (Iwate)	8.37%	1,951	23,302
Iwate	4,665	1,383	20,209	Ofunato (Iwate)	1.11%	452	40,738
Miyagi	9,505	1,878	75,391	Kesenuma (Miyagi)	1.89%	1,407	74,247
Yamagata	2	0	37	Ishinomaki (Miyagi)	2.44%	3,927	160,704
Fukushima	1,605	220	17,740	Onagawa-cho (Miyagi)	9.70%	975	10,051
Tokyo	7	0	0	Matsushima (Miyagi)	0.01%	2	15,089
Ibaraki	24	1	2,799	Soma (Fukushima)	1.21%	459	37,796
Tochigi	4	0	262				
Gunma	1		0				
Chiba	20	2	797				
Kanagawa	4	0	0				
Total	15,841	3,485	117,542				

Regarding the age of the victims<sup>6</sup> in the affected three (Iwate, Miyagi, Fukushima) prefectures, 24.0% were 70-79 years old, 22.1% were more than 80 years old, and 19.1% were between 60-69 years old. Victims aged 60 or older accounted for 65.2% of the deaths with 45.5% of total victims being men and 53.6% female.

### MENTIONED CAUSES OF HUGE DAMAGES

According to The Central Disaster Management Council, this devastating effect has resulted from three aspects: unprecedented wide range and magnitude, unexpected scale of the earthquake, and the tsunami heights that significantly exceeded the expected height.

#### Inaccurate Prediction for future earthquakes

Before the occurrence of the 2011 Great East Japan earthquake, the Central Council of Japan for Disaster Prevention had been warning about five big earthquakes, which have a high probability of occurring in near future and may cause a serious damage. Among these earthquakes, the magnitude of the earthquake at Off-Miyagi Prefecture was estimated as a medium size earthquake of magnitude 7.5. However, the magnitude of the actual event was 9.0, that is 180 times larger than the predicted earthquake. Even though the prediction was inaccurate, we would not have known what sort of earthquake could happen.

<sup>5</sup> <http://www.bousai.go.jp/jishin/chubou/higashinihon/12/3.pdf>

<sup>6</sup> Until 11th April, 2011, the National Police Agency confirmed and announced cause in the 13,135 deaths. In prefectures of Iwate/Miyagi/Fukushima, the analysis by age: Cabinet Office in Ministry of Internal Affairs and Communications.

## Tsunami is rare event with extreme consequence

Unfortunately, the tsunami wave height falls into the category of an unexpected and extraordinary curve since the earthquake occurred<sup>7</sup>. In addition, tsunami has different waves that repeat itself many times. The first wave of a tsunami is not always the drawback wave, but can be the run-up wave. Moreover, the second, third or subsequent waves can, in some cases, be bigger than the initial wave. Due to the characteristics of the tsunami, a threshold return period exists and the expected tsunami wave height and times are insignificant.

### COMPARATIVE STUDY: THE 2004 INDIAN OCEAN EARTHQUAKE

As the 2011 Great East Japan Earthquake tragically demonstrated a rare and extreme tsunami event that might have caused thousands of fatalities. In the Indian Ocean Earthquake Mw 9.3 on December 26, 2004, the tsunami devastated shores of the Indian Ocean. The number of victims, dead and missing together, is estimated 230,000<sup>8</sup>. Many researches and media mentioned the impacts and scenes of the above two disasters are similar to one another. While each disaster is unique to its time and place, the process of its recovery, reconstruction, and preventive steps against future disasters have some resemblance to each other. Therefore, cross national and comparative studies provide a lens into the mechanisms used to understand, manipulate, or evaluate them in disaster consequences and its recovery. In addition, post-disaster behavior and institutions are often a function of pre-disaster condition. It can help the researcher ascend from the initial level of exploratory case studies to a more advanced level of general theoretical models and invariances, such as causality or evolution. Whether quantitative or qualitative, comparative analysis allows us to explain the variation through the cases providing patterns that suggest the course of future events based on the past ones. In this chapter, an ongoing research, comparing disasters in India and Japan, show how comparative analysis can provide insight and improve our understanding of natural disasters. In Japan from the 2011 disaster, rubble is 4.5 times more than the 10,000,000m<sup>3</sup> in India, and is 1.8 times more than the 15 million tonnes of wreckage from the 1995 Kobe earthquake.

Table 4 Comparative Study: the 2004 Indian Ocean Tsunami

Damages		2011 Tōhoku earthquake and tsunami	2004 Indian and 2005 Nias earthquake and tsunami <sup>9</sup>
Human		Death: 15,841 / Missing: 3,485 / Injured: 5,894	Death: 127,707/ Missing: 93,285 (in 2004) Death: 979(850 in Nias) / Injured: 11,579
Housings and Buildings	Collapse	Totally: 78,641 / Half: 30,278 / Partially damages: 240,378/ Non-dwelling: 25,987	249,190 (small/medium businesses:104,500/ Houses: 139,000 / Worship places: 1,089 / School facilities: 3,415 / Health facilities: 517 / Government buildings: 669)
	Burn down	Totally and Partially: 260	
	Swept out	-	
	Inundated	Above floor level: 4,222 /Below: 4,435	-
Bridges		Roads: 3,970 / Bridges: 71/ Railways: 26	Kilometers of road destroyed: 2,618 / Bridges: 119 / Railways and Airports: 8

<sup>7</sup> On Tsunami Risk Assessment for the West Coast of Thailand (Farrokh Nadim & Thomas Glade,2006) ECI Conference on Geohazards

<sup>8</sup> International Federation of Red Cross and Red Crescent Societies, World Disasters Report. (Kumarian Press), 2005, 246 p.

<sup>9</sup> Source: SERI BUKU BRR

Embankments/ Landslides	Break of dikes: 4/ Landslides: 184	Ports destroyed: 22
Tsunami Waste	27million ton= <b>45,762,711m<sup>3</sup></b> (*average 0.59 t/m <sup>3</sup> )	400,000 m <sup>3</sup> (max: <b>10,000,000 m<sup>3</sup></b> )

On March 21<sup>st</sup>, the World Bank estimated that Japan's massive earthquake and tsunami could cost its economy up to \$235 billion, or four percent of output with reconstruction that could take five years. By contrast, the damage resulting from the 1995 temblor totaled around 10 trillion yen. Hyogo prefecture, which took a big hit, accounted for about four percent of the nation's total output at the time. But, the prefectures of Aomori, Iwate, Miyagi, Fukushima and Ibaraki, which bore the brunt of the recent quake, make up roughly seven percent of national output, leaving a larger mark on the overall domestic economy. Moreover, a heavy concentration of parts and materials manufacturers make their home in northeastern Japan and other disaster-stricken areas closer to Tokyo, resulting in shortage of supplies to a wide range of industries.

Table 5 Comparative Study: the 1995 Kobe earthquake

	The 2011 Great East Japan Earthquake	The 1995 Kobe earthquake
Damage	\$122 to 235 billion (2.5 to 4 percent of GDP)	\$100 billion (around 2 percent of GDP)
Death toll	15,214 (dead and mission)	6,434
Cost to private insurance	\$14-33 billion* *Note: AIR World estimate	\$783 million
National budget for reconstruction	\$12 billion from current budget much more FY 2011	\$38 billion over 2 fiscal years

Shown in Table 6, recoveries came despite the different levels of domestic and international aid to individuals, families, and businesses. It reveals that although Tamil Nadu was the poorest of the three, its business, shops, and housing rebounded with more resilience than New Orleans. Furthermore, Kobe did quite well despite immense damage, both in terms of deaths (6,500, the highest of these three) and property damage (\$ 180 billion, the highest again).

Table 6 One year after the disaster

Case	Business Sector	Shops / Schools	Housing
Kobe, Japan	80% experts, 90% manufacturing restored	80% shops, majority of schools reopened	Close to 85% in permanent housing
Tamil Nadu, India	Almost all fishermen back at work	Old schools rebuilt, new schools created	50% housing restored
New Orleans, LA	Unemployment at double the national average	50% schools, 40% of shops rebuilt	100,000 households in trailers
Tohoku, Japan <sup>11</sup>	24% Agriculture, 66% of Fisher ports restored	Industrial Production Index: 86.5 in affected areas (before disaster: 96.9) / 90.4 in other (97.9)	68% of tsunami waste removed. 52,182 households in temporary houses (678 in shelter)

<sup>10</sup> Inoue et al. (2007) estimated debris volume/weight: an average specific gravity of 0.59 t/m<sup>3</sup> during transportation.

<sup>11</sup> METI announced ([http://www.reconstruction.go.jp/topics/120116\\_sashikae%28data%29.pdf](http://www.reconstruction.go.jp/topics/120116_sashikae%28data%29.pdf))

## DISASTER MITIGATION STRATEGY

The past decade has shown an increase in the severity of natural disasters: during the period in 2004–2007, nine earthquakes of magnitude 8 or greater occurred in the Indian and Pacific Oceans. All of these natural disasters generated tsunami in which six were large enough to cause damages. While it is impossible to prevent a natural disaster from occurring, risk of damages can be prevented or reduced. This indicates that the human behavior plays a significant role in natural disaster preparedness, as well as structural and non-structural efforts.

### Disaster mitigation

Mitigation plans form the foundation for a community's long-term strategy to reduce disaster losses and break the cycle of disaster damage, reconstruction, and repeated damage. Hamada and Yun (2011) stated the following measures and researcher should be strongly promoted: a) survey on traces of historical tsunamis in the world from geological view point, b) establishment of information gathering and transfer system to grasp the situation of wide spread tsunami-hit areas, c) research on tsunami resistant buildings and infrastructures, d) town planning to strengthen the tsunami resistance (evacuation, construction tsunami resistant buildings, selection of residential areas, etc.), e) relief activity immediately after the disaster (evacuation warning, tsunami warning), f) enforcement of resistance of lifeline systems and quick recovery, and g) Disaster education and training.

- Structural mitigation (Hardware-side efforts): structural safety measures by constructing facilities for disaster prevention. For example, strengthening buildings and infrastructure exposed to hazards by means of building codes, engineering design, and construction practices to increase the resilience and damage resistance of the structures, as well as building protective structures such as dams, levees and seawalls
- Nonstructural mitigation (Software-side efforts): avoiding hazardous areas by directing new developments away from the known risky locations (e.g. hazard maps). This can be done through land use plans and regulations; in addition, relocate the developments with existing damages to safe areas following a disaster. Public education can emphasize knowledge and skills to help identify items that can slide and fall, to secure tall and heavy furniture, electronics and appliances, to keep exit pathways clear, fasten hanging objects, store heavy objects lower down, place beds away from windows, and use tempered glass.

In order to minimize the damages from a large-scale disaster, structural and non-structural measures should be considered and implemented. Moreover, based on the results of post-disaster surveys, human behavior plays a significant role in natural disaster preparedness, as well as structural and non-structural efforts.

- Behaviors on evacuation: response skills and provisions against disasters. In spite of tsunami warning system in Japan, people experiencing the disaster showed unexpected responses. According to Weathernews survey, only 11% of people immediately evacuated from the affected coastal areas. Moreover, Cabinet Office in Japan commented that it is necessary to review assigned evacuation buildings and locations to see whether they are suitable for people.

The damage of the Great East Japan Earthquake is still being adequately investigated and analyzed, and improvements will be made. In addition, three efforts should merge together to find linkages between them. Furthermore, key variables will be examined for quantitatively assessing the effectiveness of promoting disaster management measures.

### Structural investigation

Much of works on infrastructure in disaster focused on understanding the mechanics of how components of infrastructure systems (e.g., bridge piers) perform when subject to extreme forces or conditions. According to the investigation report from the Japan Bridge Association (JBA), 190 bridges (6%, higher than I level) of total 3,004 targeted ones were clarified to need some treatment for

trafficability (走行性), and 299 bridges (10%, over than B level) were judged of necessary repairs for load resistant capacity (耐荷性)<sup>12</sup>. Moreover, most wooden houses on the flat affected area were entirely flooded. Reinforced concrete (RC) buildings were damaged, but it did not collapse. Also, a number of destroyed vehicles, ships, and houses were observed to be floating out on the road<sup>13</sup>. Some of buildings and concrete bridges which located in the tsunami inundated area survived from the tsunami attack as shown in Figure 1. The concrete building shown in Figure 1 has a five-story, and the fifth floor was flooded. In other words, the water flew through the whole building. However, any structural damage to the super structure and concrete piles foundation was not found.



Figure 1 Survived a Five-story Concrete Building at Rikuzentakada, Iwate Prefecture in Japan(2011)



Figure 2 Survived the Baiturrahman Mosque, Banda Aceh in Indonesia (2004)

Same thing was observed in Banda Ache of Indonesia during the 2004 Indian Ocean Tsunami. Figure 2 shows a survived mosque from the tsunami, which located along the shoreline. The examples of survived buildings shown in Figure 1 and Figure 2 suggest us a possibility of the construction of concrete buildings which can withstand tsunami attack. Then, when those kinds of characters apply to larger and taller building along the shoreline, the building can be a safe haven for evacuees from tsunami. Moreover, lots of bridges survived the tsunami as shown Figure 3. This bridge was constructed by steel girders with concrete slab for a road. The tsunami exceeded the bridge's height, but no structural damage was observed. Same thing was reported from the Indonesia in 2004. A concrete bridge in Band Ache shown in Figure 4 is also entirely survived from the tsunami. This bridge has concrete shear keys to prevent lateral movements of the girder, which might resist tsunami force. The examples shown in Figure 3 and Figure 4 also give us some insights into the possibility of the construction of bridges against tsunami.



Figure 3 Survived the Bridge in Japan (2011)



Figure 4 Survived the Concrete Bridge at Banda Aceh in Indonesia (2004)

<sup>12</sup> [http://www.jasbc.or.jp/images/imageparts/title/release/ppt/2011/H23\\_0\\_1.pdf](http://www.jasbc.or.jp/images/imageparts/title/release/ppt/2011/H23_0_1.pdf)

<sup>13</sup> <http://www.pari.go.jp/en/files/items/3496/File/20110325.pdf>

## Non-structural investigation

### *Tsunami Warning System*

The Japanese Tsunami Warning Center established back in 1952 and is being maintained by the Japan Meteorological Agency (JMA). The agency operates about 187<sup>14</sup> seismic stations, 42 real-time observations, and monitors the water level stations<sup>15</sup>. On March 11, 2011, JMA provided the information, within three minutes after the earthquake had occurred, to all the areas that were expecting severe treat. To maximize the time for evacuation, the first warning was released quickly<sup>16</sup>. 28 minutes later, the second report was announced with the expected height of the tsunami being more than 10 meters. Table 7 shows the tsunami warning system operation.

Table 7 Tsunami Warning Situation in Kesenuma city on March 11, 2011<sup>17</sup>

Time	Contents	Remarks
14:46	Earthquake occurred (Japanese Seismic intensity, 震度6弱)	Disaster Response & Recovery Headquarters was established
14:46	Power in the government office and whole city was out	
14:48	<b>Radio announcement from disaster prevention: "There is risk of tsunami, evacuate to the higher place"</b>	
14:49	<b>JMA announced big-tsunami warning</b>	Arrival expectation: 6m of tsunami in the prefecture would reach around 15:00
14:52	<b>Evacuation commands to citizens by radio announcement from disaster prevention</b>	Approximately 30 times of evacuation command announced
15:00	<b>6 meter of big-tsunami alarm is officially announced</b>	
15:20	<b>JMA announced alarm of big-tsunami with more than 10 meter</b>	
15:24	Miyagi Prefecture identified tsunami of 10 m or more, at 15:14 evacuation command announced	
15:30	Oil tank outflow. Black smoke started from behind the country government office building(国合同庁舎)	
16:35	200 people evacuated to the prefectural government office building (県合同庁舎)	120 people evacuated to the country government office building(国合同庁舎)
17:40	<b>Magnitude is revised to 8.8</b>	
17:50	Fire at sea occurred	
19:13	People evacuated to the roof of the central community center (1 <sup>st</sup> floor was flooded) and to Yayoi food company	450 people in central community center, 400 people in Yayoi food company
22:09	Evacuated to the roof of Mukainada Senior High School	49 people evacuated

### *Disaster prevention training*

Ministry of Education, Culture, Sports, Science and Technology (MEXT) has been developed disaster education to foster the viability with three major efforts: effort in nation, effort in the community, and effort in school. From 2008 to 2010, it conducted a project to support regional disaster education business that is consist of (1) writing disaster reduction-related materials, (2) design training and education curriculum development for school staff including teacher, and (3) development more practical disaster education programs. According to survey (Kamaishi's shelters), 21% of respondents (total: 322) answered the experiences of disaster education and drill<sup>18</sup>.

<sup>14</sup> <http://www.jma.go.jp/jma/press/1110/07a/tsunami-kansoku.pdf> (184 →187, JMA released in October 7, 2011)

<sup>15</sup> [http://nowphas.mlit.go.jp/index\\_eng.html](http://nowphas.mlit.go.jp/index_eng.html)

<sup>16</sup> <http://www.bousai.go.jp/jishin/chubou/higashinohon/1/2.pdf>

<sup>17</sup> [http://www.fdma.go.jp/disaster/chiikibousai\\_kento/houkokusyo/sanko-2-2-1.pdf](http://www.fdma.go.jp/disaster/chiikibousai_kento/houkokusyo/sanko-2-2-1.pdf)

<sup>18</sup> Ministry of Land, Infrastructure, Transport and Tourism (2011.7.6)



### ***Kamaishi city: education for children***

Since 2005, Kamaishi has been implementing training sessions with active cooperation by Professor Katada in Gunma University. Its slogan is "safety of the children." Three evacuation principles for the disaster prevention training are the following: (1) do not trust unquestioningly in any experience and assumption, (2) do your best under the situation, (3) take the lead and encourage evacuation. As the result, 5 out of 3,244 children are victims (survival rate: 99.8%) while the casualty is nearly 1,000 in Kamaishi. Even though it has been introduced as "a miracle of Kamaishi," the staffs mentioned it is not just a miracle. It was an accomplishment of disaster prevention efforts.

### ***Education in Kesennuma city***

Kesennuma city delivers the education under the slogan "disaster mitigation by self-act and help one another." The city developed a program and its material while considering age, curriculum, and location etc. In order to enforce how to effectively react to the disasters, the city conducts disaster prevention workshops and lectures for the public and elementary schools. Roughly 30 hours per year are allotted for disaster prevention education at school. Lower grades levels are connected to the regional upper grades that are in charge of leading the lower grades during disasters. Therefore, twelve out of 6,054 students are victims by this disaster.

### **Behavior of evacuation**

Residents' disaster preparedness capabilities need to be enhanced and combined with other structural and non-structural aspects. Evacuation actions taken by residents are fundamental to human damage mitigation measures against disaster. For example, the initial step in protecting human lives from a tsunami is evacuating to a higher ground swiftly and autonomously, without hesitation, as soon as a strong or an extended shaking is felt.

Although the engineering effects of the earthquakes within the individual buildings have been extensively studied in recent years, little work has been done in documenting precisely how people behave during an earthquake. More detailed information is needed because knowledge of what people do during and immediately after a severe earthquake can assist researchers in giving advice and training residents on how to act in ways that will reduce panic, injury or death in future events.

### ***Studies of residents' behaviors in the 2011 Great East Japan Earthquake***

Using a questionnaire designed to grasp the relationship between evacuation behaviors and tsunami damages, the investigators interviewed 870 refugees from Iwate, Miyagi, and Fukushima prefecture. Then, they analyzed their behaviors (Joint investigation by JMA, Fire and Disaster Management Agency, and Cabinet Office of Japan)<sup>19</sup>. The results revealed that among 496 immediate evacuees and 267 delayed evacuees, 48 percent said they instinctively knew a big tsunami could come after this kind of shaking. 35 percent of evacuees were motivated to evacuate due to the appeals from people around them such as their family (20%) and neighbor (15%). Lastly, 16 percent evacuated because of the tsunami alarms warning. On the other hand, 31 percent of the evacuees, after some hesitation, and 11 percent of respondents, who did not evacuate, were not able to withdraw immediately. The 34 percent went back to their house to look for or pick up family members. Moreover, 11 percent believed that it was not possible for a big tsunami to come to their area, given the past experiences, or other reasons, like due to the strong breakwaters. However, the survey illustrated a worst case scenario. The evacuation led the some hesitant evacuees to go to an undesignated location or to the upper floors of the same building. Moreover, 57 percent of them evacuated using their cars; and more than one third of their cars were in congestion.

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<sup>19</sup> Survey participants: 870 refugees who have been in Iwate, Miyagi, and the coastal area of Fukushima prefecture (Iwate: 391, Miyagi: 385, Fukushima: 94) / Research method: visiting the temporary housing (dwelling) /shelters and conducting interview face to face (bring the questionnaires and write the answers / Period: from early July by the end of July, 9:00 am - 6:00 pm, 30 minutes to 60 minutes per a person

### Previous researches

This is an overview of the tsunami in Japan since 1980. Twenty eight times of alarms were released; and four out of those alarms were for tsunami with more than 3 meters. Table 8 illustrates the details of the four big tsunamis that were announced along with the earthquake, as well as its results of the conducted surveys from the affected residents.

Table 8 Comparative Study: Evacuation behaviors during earthquake and tsunami

Name of the earthquake	Middle Japan Sea Earthquake	Hokkaido-Nansei-Okai Earthquake	Middle part coast earthquake in Chile	2011
Time of occurrence	1983.5.26 11:59	1993.7.12 22:17	2010.2.27 15:34	2011.3.11 14:46
Magnitude	7.7	7.8	8.8(*1)	9.0
Tsunami warning	Big tsunami	Big tsunami	Big tsunami	Big tsunami
Max tsunami height (place)	1.94m (Noshirokou)	1.75m and more (Esashi)	1.28m (Susakikou)	9.3m (Soma)
Number of Fatalities and missing	104	230	0	19,225
Investigation place (the number of the samples)	Noshiroshi (1,000)	Okushirichou (204)	36 cities&village in Aomori & Iwate & Miyagi pre.(5000)	870 (3 Prefectures: Iwate/Miyagi/Fukushima Prefecture)
Evacuation Rate (%)	3.6%	89.2%	37.5%	57%
Opportunity of evacuation	-	1. Experience of Middle Japan Sea Earthquake (50.5%) 2. Appeal from the family (39.0%) 3. Appeal from relative, neighborhood (19.8%)	1. Appeal from the cities and towns (47.1%) 2. Experience of 1980 Chile earthquake and tsunami (44.0%) 3. Big-tsunami alarm (41.3%)	1. Instinctive thought that tsunami will come after such a big shaking (48%). 2. Appeal of family, neighborhood (20%) 3. Hear or see big- tsunami warning (16%)
Reason of not evacuating	-	-	1. Thought that place would never be inundated from tsunami (52.7%) 2. The tsunami height of other area was not high (19.2%) 3. There was big-tsunami alarm, but they thought only the tsunami smaller than 3m (16.5%)	1. Go back home (22%) 2. Look for or go to meet family (21%) 3. Check their family's safety (13%)
Issues on evacuation	Approximately 40% of the people who heard a tsunami warning (54.2%) replied that such a big tsunami would never come here.	The obtained ratio of information evacuation was low (18.1%), but approximately 80% of people evacuated before tsunami arrival because of the experience of 1983 Middle Japan Sea Earthquake.	In spite of a remote place earthquake, lifeline and well-functioned communication infrastructure, evacuation rate remained in just 37.5%.	Compared to the evacuation rate in 1993, the rate in 2011 is relatively low. Based on surveys in 2006 and 2007, the evacuation rate in 2006 was nearly half (46.7%) and one in 2007 was 31.8%. Likewise, despite a big tsunami alarm in 2010, the real wave was lesser than expectation. One year later, the big-tsunami alarm might remind of the last insignificant tsunami.

In particular, the evacuation rate in 1993 was 89.2% compared to the rate in 2011, which was relatively low at 57%. Considering the results from surveys in 2006 and 2007, the evacuation rate in 2006 was nearly half (46.7%) the one in 2007 (31.8%). The reason why they did not evacuate in 2007 was because the tsunami in 2006 was not insignificantly big. It was smaller than estimated height (more than 3m). Likewise, although there was a big tsunami alarm in 2010, the actual wave was less than the announced height. Approximately one year later, the same big tsunami alarm might have reminded people of the last trivial details of the tsunami height. Therefore, this was one of the reasons why they did not evacuate.

### Data from Weather news

From March 14, 2011 to May 10, 2011, information were gathered from 88,604 witnesses from Tohoku (9,136 near the coast of Aomori/Iwate/Miyagi/Akita/Yamagata/Fukushima prefectures) to Kanto area. Seventeen-question questionnaire consists of time to learn about the tsunami and earthquake, method (e.g., TV, radio), behaviors during the event, and two open-ended questions. Weathernews, specializing in dealing with disaster data, conducted surveys and collected the data using the internet and mobile web sites called “Weather Widget”, a smart phone application.

### Methodology

The collected open-ended questions in the surveys inform us with valuable information. This study used text mining for big data analysis. Text mining, also known as text data mining or knowledge discovery from textual databases, generally refers to the process of extracting interesting and non-trivial patterns or knowledge from unstructured text documents. Some scholars argue that human discourse and action can be better explained through qualitative methods instead of natural sciences. Miles and Huberman<sup>20</sup> (1994) stated: “With qualitative data one can preserve chronological flow, see precisely which events led to which consequences, and derive fruitful explanations... Words, especially organized into incidents or stories, have a concrete, vivid, meaningful flavor that often proves far more convincing to a reader – another researcher, a policy maker, a practitioner – than pages of summarized numbers.” (p.1) For example, Adam and Muraki analyzed 250 Twitter users’ text-based posts of up to 140 characters, known as tweets, which included the word ‘earthquake’ on March 11, 2011. Through a qualitative analysis of the tweets and open-ended responses, the authors found most of the tweets in the devastated areas were about (a) warnings, (b) help requests, and (c) reports about the environment (tsunami, fire and communication) and themselves.

More than thousands of data are desired as target documents (corpus) when using text mining for analysis purposes. Therefore, using Weathernews' low data and the number of target documents are enough in this study. The four steps of analyzing the documents for this study is the following: (1) Select key words for two groups, (2) sort the comments into two groups, (3) run statistical analysis (e.g., cross-tabulation analysis or cluster analysis).

### Research Questions

Since the past studies do not provide any qualitative assessments on how people proceed to behave during the disaster, two research questions are: a) what kind of messages did they post about the earthquake? b) two groups (the death/missing, the survivors) show significant differences on behavior during disasters?

First, we qualitatively analyzed the comments sent from Tohoku area. To analyze, we ran a text mining tool in Japanese, MeCab and RMeCab, with selected key words ‘missing’, ‘corpse’, ‘dead body’ for a group of the death/missing<sup>21</sup>. Here are some of the comments from the results of MeCab.

- There were 42 refugees and two employees of the local government on the roof of town municipal office. Because of the disaster prevention radio announcement (female staff who was broadcasting is missing), it was able to know the quick invasion of tsunami. Despite bad weather, tsunami, and aftershocks, there were encouragements among refugees each other. When all of family met again, tears did not stop.
- Grandparent picked up their grandchild from kindergarten then went back to house to get luggage. They left the grandson in the car and the tsunami swept out them.

The following table illustrates an example of the results from data based on the Japanese words, its translation into English, and the frequency of the words.

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<sup>20</sup> Miles, M.B. and Huberman, A.M. (1994) *Qualitative Data Analysis*, 2nd ed., Sage, Thousand Oakes.

<sup>21</sup> In Japanese, (行方)不明, 死体, 遺体

Word in Japanese	Word in English	Frequency of word
行方不明	Missing person	98
助かる	Be saved or be helpful	1,091
遺体	Dead body	22
家族	Family	4,506
近所	Neighborhood	3,050

It is quite difficult to interpret Japanese words when using text mining tool, even with simple word's meaning definition. For example, depending on the sentence, the word `助かる` was translated into two meanings, (1) be saved and (2) be helpful. With its definition written as `be saved`, it could be a suitable target document. On the other hand, `be helpful` is usually used for just describing the situation. Therefore, it is necessary to consider how to classify meaningful comments for the analysis.

### Gather key words and key sentences

In order to figure out and classify meaningful sentences, it was difficult to extract from the first Weathernews data. Many of the comments did not contain any actions and expressions of various emotions. 89.8 % of the comments were reporting about the self or the environment, one percent of the comments were concerns and condolences, two percent of the data were expressed thank for helping and for being saved them/their family to God. Negative behaviors included comments were 3.5 % of the target data and positive behavior ones were 3.7 percent. There, this study analyzed the selected 107 comments regarding death or missing people in the five prefectures (Miyagi 74, Iwate 18, Fukushima 9, Ibaraki 4, Chiba 2). These comments were from the witnesses, which was conducted by Weathernews within the survey period from May 18, 2011 to June 12, 2011. Here are some comments:

- Fire fighter passed away. He went to close the floodgates, but the gate entirely disappeared with him. (30-39 years old man, Rikuzentakada, Iwate prefecture)
- Appeal for evacuation to neighborhood, but he could not evacuate himself. (60 years old man, Ishinomaki, Miyagi prefecture)

### Result: Ranking of behaviors

In this study, negative behaviors are defined as someone who had that action in which it led to his/her death. Otherwise, it means that people had positive behaviors. Some comments expressed both positive and negative behaviors. Therefore, 183 meaningful words and/or sentences were extracted from the comments by an expert in this field, and classified the comments into groups of negative behaviors, positive behaviors, reporting self/environment, concern and condolences, and thank to people or God. In addition, the MeCab and RMeCab were run with the chosen words. As a result, the frequencies of the each of the behaviors create groups (clusters) according to the definition. The following Table 9 and Table 10 summarize the ranks of the negative and positive behaviors based on the frequency of those behaviors.

Table 9 Ranking of the negative behaviors

Rank	Behavior	Frequency
1	Be tied up on the road traffic jam	26.3%
2	Help other people	22.4%
3	Do work and duty for rescue	13.9%
4	Do not evacuate due to no/wrong information	13.7%
5	Find their family/relatives	9.7%
6	Ignore the warning based on the past experiences	8.9%
7	Leave from the assigned place	5.1%

Table 10 Ranking of the positive behaviors

Rank	Behavior	Frequency
1	Immediate Evacuate	52.5%
2	Follow other people direction	39.4%
3	Remember former disasters	8.1%

Based on Table 10, it is clear that early evacuation is vital for safe state from tsunamis. Moreover, some people who were not expecting a tsunami managed to evacuate as a result of having been verbally warned by those around them. Therefore, it is crucial for residents who could be affected by tsunamis to understand the importance of early evacuation. Although tsunami warning was announced, shown in Table 9, many people who were in plains did not have time to evacuate to higher ground. There were also cases of people losing their lives due to failing to perform necessary evacuation behaviors. Furthermore, it is important staying in safe and assigned places as well. Figure 5 presents the number of people in refuge, which shows the people's behaviors during the 2010 Chile earthquake. After tsunami alarms, people relocated in refuge, but the number of people in refuge declined over time. Lots of people came back home while the tsunami warning was still coming out. They went back to their houses before the tsunami completely came to an end. However, Table 9 illustrates those negative behavior led to his/her irreversible risk.

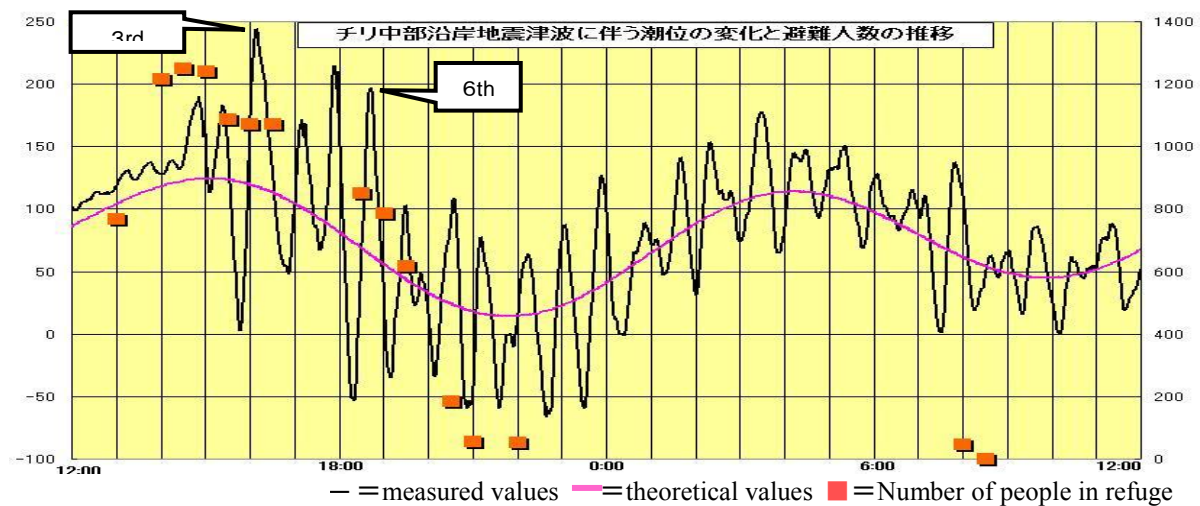


Figure 5 Number of people in refuge during the 2010 Chile Earthquake (M: 8.8) Shinmeisaki(神明崎東) in Kesenuma city (気仙沼市), Miyagi Prefecture (宮城県)

Table 11 shows the applied result of the 5,298 data (including 1,998 for the death/missing people) from Tohoku area by Weathernews.

Table 11 Sort the data into two groups based on the behavior types

Group \ Behavior	Negative Behaviors	Positive Behaviors	Total
The Death/Missing	1,543	455	1,998
The Survivor	1,711	1,587	3,298
Total	3,254	2,042	5,296

In order to verify the significant difference, the cross-tabulation analysis (or cluster analysis) was used, and the results are shown below in Table 12. The difference of behaviors between group of the death/missing and the survivor is significantly distinguished.

Table 12 Sort the data into two groups based on the behavior types

Statistic	Person $\chi^2$	Degrees of freedom	P value
Analysis	2.868	1	0.090*

## CONCLUSION

Full preparation need to be made against earthquake and tsunami since earthquake can occur anywhere in Japan. For the huge disasters, it is clear that the different approach is necessary. Instead of protecting against any loss of life, trying to save as many lives as possible becomes the most important goal. Based on the prediction for future earthquakes, countermeasures for Tokyo inland earthquakes will need to examine the earthquake hazard of the size of the 1923 Great Kanto earthquake. First thing which we have to do is to carefully grasp the whole aspect of the disaster and to deliver the exact information to the researchers in the seismological and earthquake engineering all over the world. It is important to communicate to the international community correct information on safety and security. Also, investigation reports of impacts of this catastrophic disaster will provide to people around world. Second thing is to investigate into study on the causes of the disaster. It is necessary to study what are the differences between the causes of the 2011 East Japan earthquake from the previous ones. Moreover, although tsunami warning was announced, many people who were in plains did not have time to evacuate to higher ground. There were also cases of people losing their lives due to traffic jam. It is necessary to consider a smooth evacuation way using car. Moreover, instead of relying on hardware approach such as improving and strengthening buildings, the disaster prevention puts emphasis on software approach such as improvements to warning systems and more thorough evacuation education. The following future researches are now in progress: (a) role of social network and ties have explained speed of rescue during disasters and of recovery after disaster. For example, the twitters' users retreated messages to call for help in Kessennuma city, then they could be rescued by helicopter, (b) it is necessary to modify guidelines of evacuation behaviors in disaster prevention training and drill based on actually taken actions. It is difficult changing human behavior, but the rewards are worth the effort.

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