Quick Report of Great Eastern Japan Earthquake and Tsunami

(As of 22 April 2011)

Kuniyoshi Takeuchi and Ali Chavoshian
with contribution of Shigenobu Tanaka
ICHARM, Tsukuba 305-8516, Japan

Together with all ICHARM members we pray for the victims, express heartfelt condolences to the families and friends who lost their loved ones and deep sympathy for all the people suffering.

1. Introduction

At 14:46 (05:46 UTC) on Friday, 11 March 2011 an Earthquake of Magnitude (Mw) 9.0 occurred off the Pacific Coast of Tohoku, Japan. It induced the Catastrophic Tsunami on the Pacific Coast of Tohoku and Kanto. Tsunami also hit the nuclear power plants in Fukushima and damaged the cooling system of reactors and fuel disposal storages which are still not under full control threatening people in the wide area around the site. Hundreds of aftershocks with Magnitude of 5.0 or greater jolt the affected area since then including five strong aftershocks with magnitude greater than 7.0.

According to National Police Agency, 14,084 persons are confirmed dead and 13,511 are still missing as of April 21, 2011. More than 500,000 people were displaced in the affected areas. The latest data on April 21 indicate that still 133,000 people are living in 2,486 evacuation centers. It is considered the most costly natural disaster in Japan and probably in the world.

In this quick report the easily accessible information from news media and internet was summarized on the Mega-Quick, Catastrophic Tsunami and nuclear accidents with damages and its aftermath.

2. A Chain Reaction of Disasters

It was a chain reaction of disasters triggered by a Magnitude 9.0 earthquake inducing giant Tsunami and nuclear power plants malfunctioning. Each was the unprecedented scale but the impacts were more devastating in Tsunami and nuclear malfunctioning.

2.1 The Magnitude 9.0 Earthquake and its Geophysical Nature

The maximum slip was 25 m in the area of 450 km in length and 150 km width (JMA/MRI) where the Pacific Ocean Plate sinks into under the North American Plate which ends at the northern end of the Philippines Plate off shore of Ibaraki (JAMSTEC, Yomiuri 24 March). The nearest major city to the quake was Sendai, on the main island of Honshu, 130 km away. The quake occurred 373 km from Tokyo.

The magnitude of the earthquake: M 9.0 (revised in on 13 March. It was first announced 8.4, upgraded to 8.8 on 12 March by Japan Meteorological Agency)

Seismic intensity: 7 (Maximum) in Kurihara City in Miyagi Prefecture, 6+ in 28 cities and towns in Miyagi, Fukushima, Ibaraki (including Tsukuba) and Tochigi Prefectures (Figure 1). (JMA)

Epicenter: 130 km ESE off Oshika Peninsula of Miyagi Prefecture 24 km in depth. (JMA)

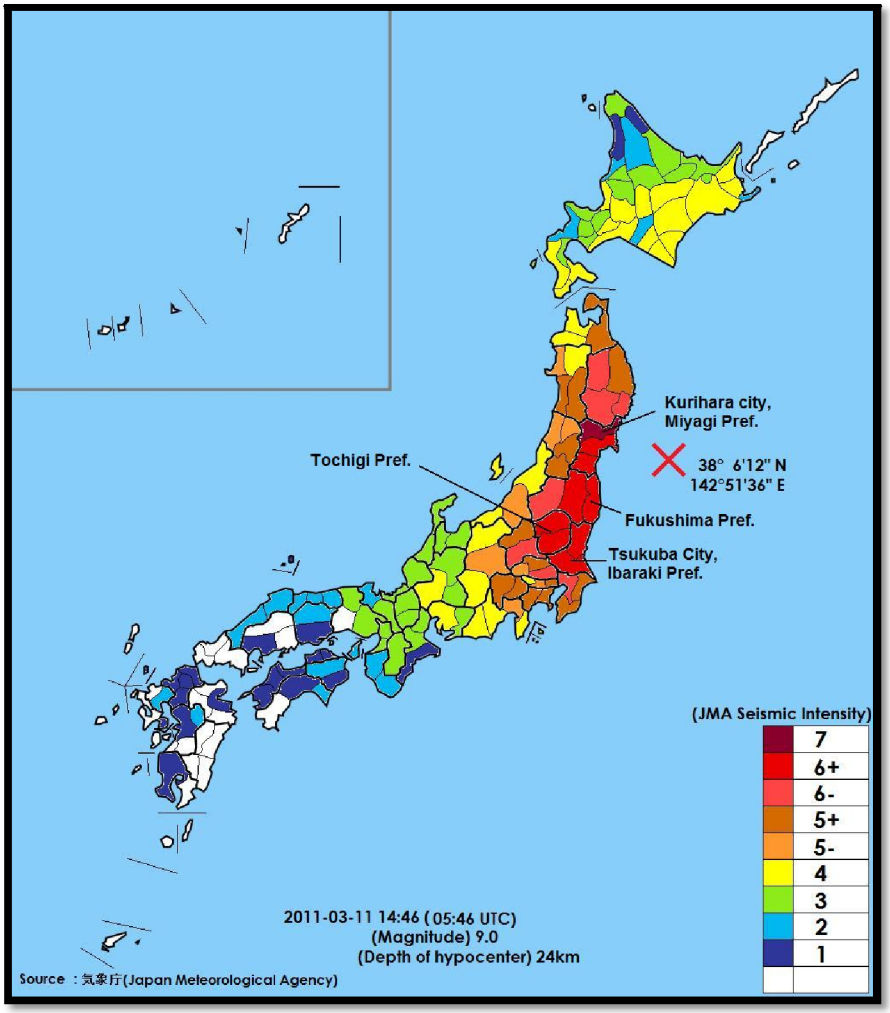


Figure 1 Seismic Intensity 7 in Kurihara city in Miyagi Prefecture

2.2 Catastrophic Tsunami

Tsunami waves hit seven times in 6 hours after the Quake (Mainichi 31 March). The number 3 was the highest. As of 4 April, 70% of the Tsunami inundated areas are still submerged (Asahi 29 March) because of land subsidence (Figure 2, 9). Largest subsidence was 116 cm at Oshika Peninsula (Asahi 10 April)

Like the 2004 Indian Ocean earthquake and tsunami, the damage by surging water, was far more deadly and destructive than the actual quake. The most decisive reason of causing the high death toll was the unexpectedly high tsunami. The tsunami dikes almost all affected cities and towns were based on much smaller tsunami heights. The tsunami height was beyond expectation and at least 64 evacuation centers were hit by Tsunami and took more than 1000 lives (Mainichi 29 March). Many people caught in the tsunami thought that they were located on high enough ground to be safe.

Figure 2 Paddy field still inundated after a week in Iwanuma, Miyagi (NILIM, 28 March 2011)

On 13 March 2011, the Japan Meteorological Agency (JMA) published details of tsunami observations recorded around the coastline of Japan following the earthquake (Table 1).

Table 1: Tsunami Warnings and Advisories

Observed Tsunami (time and height)

	First tsunami	Maximum height of tsunami
Miyako (Iwate)*	March 11, 14:48 JST +0.2m	March 11, 15:26 JST +8.5m<=
Ofunato (Iwate)*	March 11, 14:46 JST -0.2m	March 11, 15:18 JST +8.0m<=
Ishinomaki (Miyagi)*	March 11, 14:46 JST +0.1m	March 11, 15:25 JST +7.6m<=
Soma (Fukushima)*	March 11, 14:55 JST +0.3m	March 11, 15:50 JST +7.3m<=
Oarai (Ibaraki)	March 11, 15:15 JST +1.8m	March 11, 16:52 JST +4.2m
Kamaishi (Iwate)*	March 11, 14:45 JST -0.1m	March 11, 15:21 JST +4.1m<=
Mutsu (Aomori)	March 11, 15:20 JST -0.1m	March 11, 18:16 JST +2.9m
Nemuro (Hokkaido)	March 11, 15:34 JST slight	March 11, 15:57 JST +2.8m
Tokachi (Hokkaido)*	March 11, 15:26 JST -0.2m	March 11, 15:57 JST +2.8m<=
Urakawa (Hokkaido)	March 11, 15:19 JST -0.2m	March 11, 16:42 JST +2.7m

* Maximum height of tsumami cannot be retrieved so far due to the troubles.
Actual maximum height might be higher.

These readings were obtained from recording stations maintained by the JMA around the coastline of Japan. JMA bulletin also included the caveat that "At some parts of the coasts, tsunamis may be higher than those observed at the observation sites." The timing of the earliest recorded tsunami maximum readings ranged from 15:12 to 15:21, between 26 and 35 minutes after the earthquake had struck.

On 23 March 2011, Port and Airport Research Institute reported tsunami height by visiting the port sites or by telemetry from offshore as follows:

- Port of Hachinohe 5~6 m

- Port of Hachinohe area 8~9 m
- Port of Kuji 8~9 m
- Mooring GPS wave height meter at offshore of central Iwate (Miyako) 6 m
- Port of Kamaishi 7~9 m
- Mooring GPS wave height meter at offshore of southern Iwate (Kamaishi) 6.5 m
- Port of Ōfunato 9.5 m
- Run up height, port of Ōfunato area 24 m
- Mooring GPS wave height meter at offshore of northern Miyagi 5.6 m
- Fishery port of Onagawa 15 m
- Port of Ishinomaki 5 m
- Shiogama section of Shiogama-Sendai port 4 m
- Sendai section of Shiogama-Sendai port 8 m
- Sendai Airport area 12 m

A joint research team from Yokohama National University and the University of Tokyo also reported that the tsunami at Ryōri Bay (綾里白浜), Ōfunato was about 30 m high (JSCE/CEC). They found fishing equipment scattered on the high cliff above the bay. At Tarō, Iwate, a University of Tokyo researcher reported an estimated tsunami height of 37.9 m reached the slope of a mountain some 200 m away from the coastline (Yomiuri 4 April). This height is deemed the second record in Japan historically, as of reporting date, that follows 38.2 m of 1896 Meiji-Sanriku earthquake.

2.3 Nuclear Power Plants Malfunction

There are four nuclear power stations in the affected area, Onagawa in Miyagi, Fukushima Dai-ichi and Fukushima Dai-ni in Fukushima and Tokai in Ibaraki prefectures (see the map in figure 6). All are built on the Pacific coast. However, only Fukushima Dai-ichi and Dai-ni got damaged by Tsunami. The Onagawa plant was built over 15 m high land considering 869 Jogan Tsunami by estimated M8.5 Earthquake. But Fukushima Dai-ichi and Dai-ni were built only considering 1896 and 1933 Tsunamis which were low at their sites. The Dai-ni is now under the control but Dai-ichi is not yet as of 22 April.

Fukushima Dai-ichi Plant: The sea dikes were 5.7 m high and the tsunami was over 14 m. All 6 units of power plants lost their sea water pumps as they were exposed open air and emergency diesel generator were damaged as they were in weak buildings.

Fukushima Dai-ni Plant: By the Tsunami of 11 March, all 4 units (each 1100 MW) lost the electricity supply and the cooling system got down. On 12 March people within 10 km was instructed to evacuate. But by 15 March the situation came back normal. The cooling system recovered and the reactor completely stopped in cool. It had the sea dike as low as 5.2 m while the tsunami was over 14 m. But only the sea water pumps for cooling were destroyed and the emergency diesel electricity generators were not damaged as they were protected in proper buildings which

made a difference from Dai-ichi.

- Kohnago fish was found with 4080 Bq/kg (allowance 2000 Bq/kg) off shore Ibaraki Prefecture and all the fishing in this area stopped. (Asahi on 6 April)

- Radiation level just outside of 30 km warning area: Iidate village: 6.482 mili Sievert by 4 April, 0.0155 Sv/d on 4 April, Namie: 10.99 mSv, 0.0273 mSv/d. Note that one lung X-ray: 0.05 mSv, one Tokyo-New York round trip: 0.19 mSv.

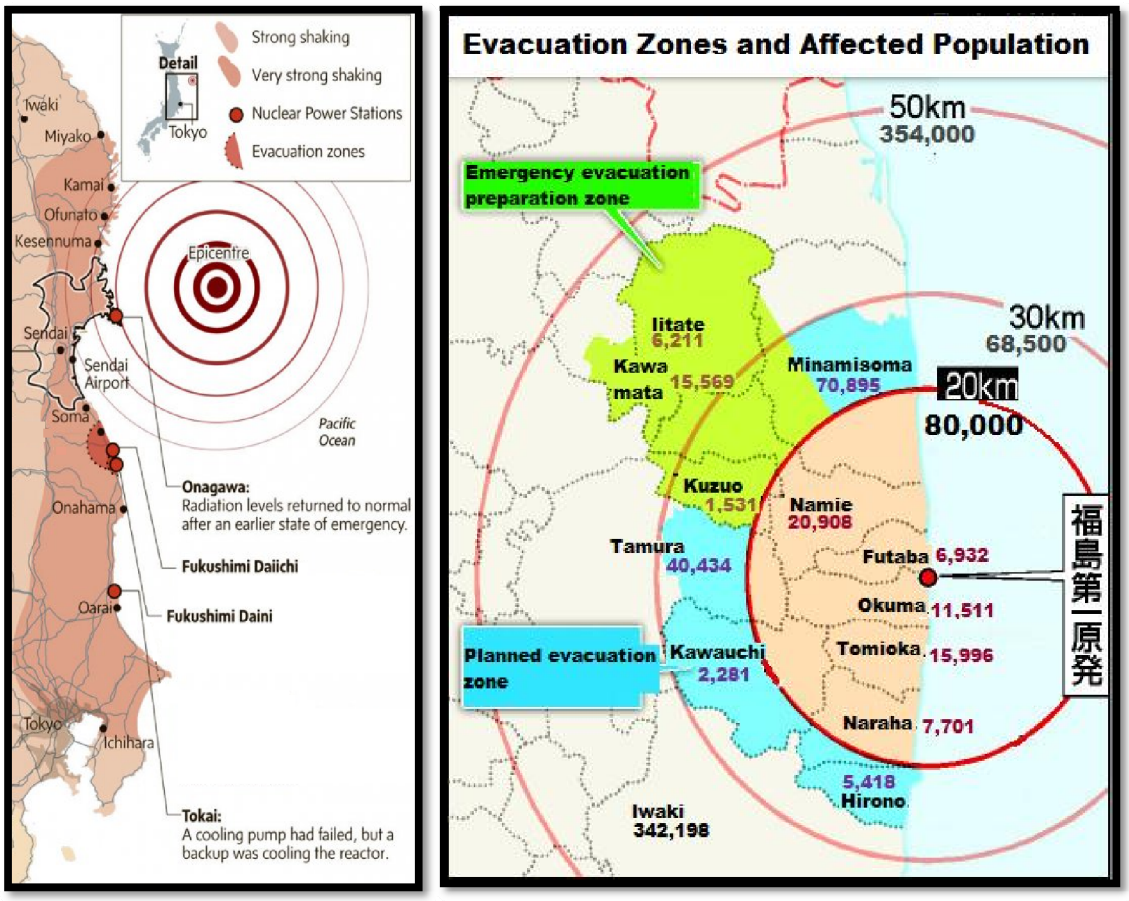


Figure 3 Location map of nuclear power plants and affected population in evacuation zones

2.4 Aftershocks: The main earthquake was preceded by a number of large foreshocks, and hundreds of aftershocks were reported. The first major foreshock was a 7.2 M event on 9 March, approximately 40 km from the location of the 11 March quake, with another three on the same day in excess of 6.0 M.

Over eight hundred aftershocks of magnitude 4.5 or greater have occurred since the initial quake with about 68 being over 6.0 M and five over 7.0 M.

A 7.7 M and a 7.9 M quake occurred on March 11 and the third one on 7 April 2011, with M 7.4. Its epicenter was underwater, 66 km off the coast of Sendai. At least four people were killed, and electricity was cut off across much of northern Japan including the loss of external power to Higashidori Nuclear Power Plant and Rokkasho Reprocessing Plant. A M 7.0 aftershock on 11 April 2011 killed four more

people and seriously injured three others.

See the table 2 as of 15:00 JST, 20 April 2011.

Table 2 The largest aftershock and major before shock and aftershocks greater than 5M (JMA)

Largest Aftershock	Magnitude 7.7 at 11 March 2011 15:15 JST (06:15 UTC)
Magnitude 7 or greater: 5 shocks one on March 9, two on March 11, one on April 7 and one on April 11	
Magnitude 6 or greater: 72 shocks	
Magnitude 5 or greater: 423 shocks	

3. Damages and Aftermath

3.1 Human Losses: Cause of Death, Demography and Gender

The Casualty update from the National Police Agency of Japan on April 21 at 8 PM (20:00) local Japanese time are 14,084 fatalities and 13,511 missing. See the table 3 for the latest casualty for each affected areas.

Table 3: Human Casualty

	Fatalities	Missing	Injuries
Hokkaido	1		3
Aomori	3	1	61
Iwate	4,058	3,759	165
Miyagi	8,541	7,789	3,436
Akita			12
Yamagata	2		29
Fukushima	1,422	1,959	227
Tokyo	7		90
Ibaraki	23	1	693
Tochigi	4		135
Gunma	1		35
Saitama			42
Chiba	18	2	224
Kanagawa	4		139
Niigata			3
Yamanashi			2
Shizuoka			4
Kochi			1
Total	**14,084**	**13,511**	**5,302**

According to NPA, among the dead 13,135, 92.5 percent of the victims in the most severely hit prefectures of Iwate, Miyagi and Fukushima died from drowning, while 65.2 percent of them were

aged 60 or older. The NPA supposed that because the tsunami occurred during the day time of a weekday, elderly were left at home and could not escape while many younger generations might evacuate in group either at school or at work. (Yomiuri 20 Apr). See the Figure 4 for more detail as of April 21. The ratio of the dead aged 60 or older to the total victims exceeds by far the ratios of residents in the age group in many municipalities located along the coastlines.

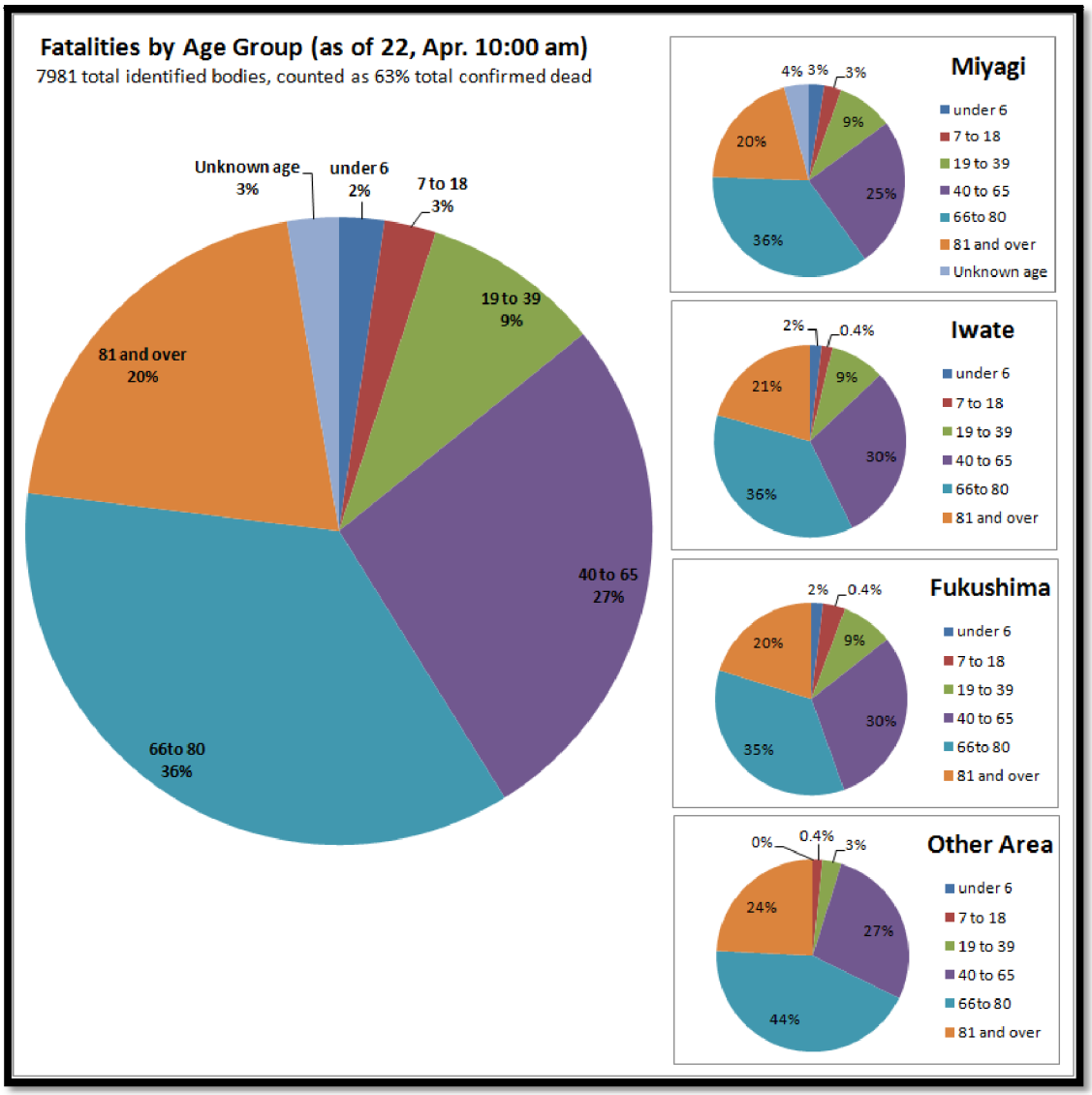


Figure 4 Demography of causalities as of April 21

As of April 21, out of 14,084 quake victims in the three prefectures on whom the police have completed autopsies, 93.5 percent died from drowning. Of the remainder, 1.1 percent died of burns and 3.4 percent either crushed to death or died from injuries, while the causes of deaths for 2 percent could not be identified. The percentage of deaths by drowning was the highest in Miyagi at 95.7 percent, followed by 88.3 percent in Iwate and 87 percent in Fukushima.

Deaths by drowning as well as the large majority of crush and injury deaths were the result of the

massive tsunami, highlighting the difference between the 1995 Great Hanshin Earthquake, in which over 80 percent of the victims died in collapsed houses (Mainichi 29 April).

See the figure 5 for gender analysis of causalities.

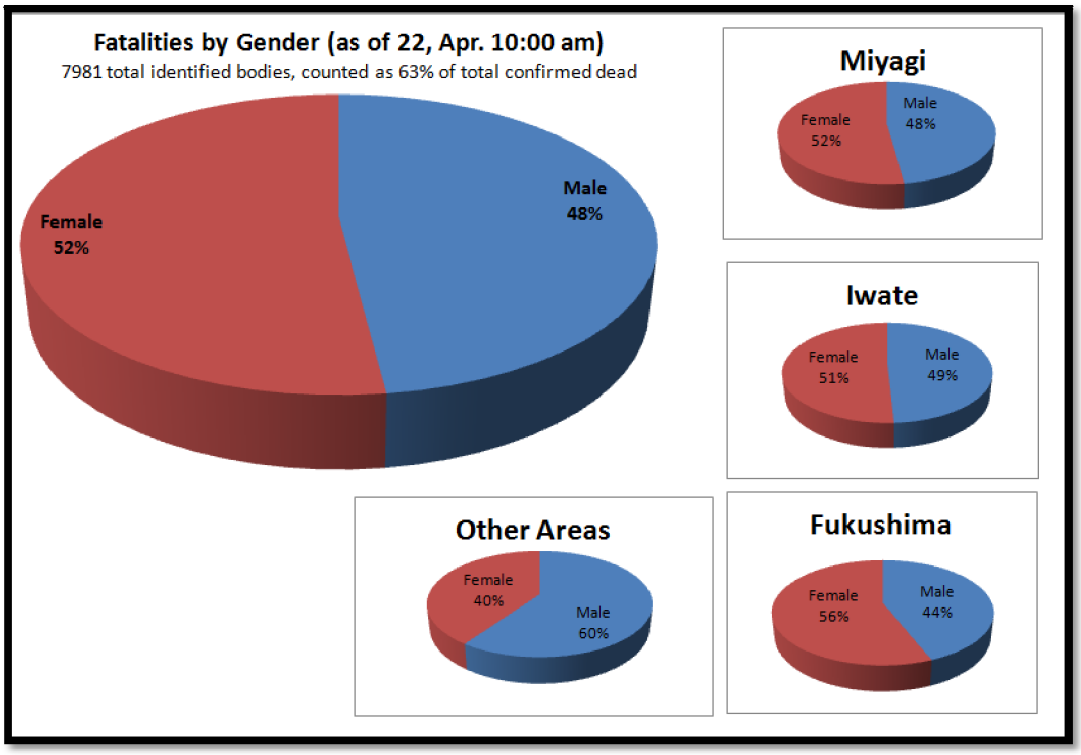


Figure 5 Gender of causalities as of April 21

Some lesson learned:

- "Tsunami Tendenko" (save yourself without caring even parents at Tsunami) was a lesson learnt from Sanriku Tsunami of 1896. In Taro town in Miyako-shi, 1859 people died and only 36 survived. This experience saved many school children's life in Kamaishi and Ofunato. In an elementary school of 184 children in Kamaishi, 80 percent of them already returned home as class hours were shortened at the end of the semester, still all the children were safe. However, it is rather difficult for adults to follow such an inhuman practice and in fact many didn't trying to help each other and paid its cost by their lives. (Yomiuri 28 March)
- Many people tried to leave by cars which made damages larger, observed in Sendai and Kesen-numa. Policemen warned drivers to leave their cars and run away on foot but few followed. Some in Soma-shi on the other hand was saved by driving a car as his wife was sick. Only in Miyagi alone, 146 000 cars were flown away. (Asahi 1 April)
- A stone monument of "no house from here below" built after 1933 Showa Sanriku Tsunami saved the people who observed the lesson in Aneyoshi, Miyako-shi. By the Tsunami of 1896 and 1933, the survivors were only 2 and 4 in the village, respectively. (Yomiuri 30 March)

Figure 6 A stone monument in Aneyoshi, Miyako-shi built in 1933 reads: Build houses on higher ground for children and children's children to live safe and sound. Remember the huge tsunamis that totally wiped out our village. Never, ever, build houses below this stone.

- Hudai village in Sanriku Coast between Kuji and Miyako had no effect of Tsunami although it got as high Tsunami all others. It built 10.5m dike after 1933 Tsunami but upgraded to 15.5m dike in responding the 1896 Tsunami. Taro-cho on the other hand hit badly again as its dike was left 10.0m responding 1933 Tsunami and not that of 1896.
- The Sendai East Road is running south to north along the coast line of Sendai City, Miyagi Prefecture. It served as a tsunami dike and saved 250 people in Wakakusa-ku where it is 5.6-8.8 m high and about 3 km away from the coast. The road was in the tsunami hazard area and the residents had been requesting, with 15 000 people's signature, the Road management company to designate as the evacuation area. But it was not accepted as it is a motor highway. If it was, more people out of 530 dead would have been saved. (Mainichi 8 April)

3.2 Direct Economic Damages

Direct economic losses are estimated as Japanese ¥16 to 25 Trillion excluding the effects of nuclear plants accidents (23 March by Minister of State for Economic & Fiscal Policy). A World Bank report released on 21 March shows the Japanese disaster to be one of the most costly in recent memory. The report estimates the quake's economic toll at US$122 to 235 billion, and furthermore estimating that the country could take five years to recover.

Insurance (Nikkei, 4 April)

Earthquake insurance in Japan can be bought only through fire insurance with extra premium. If the total payment of insurance companies exceeds ¥115B, the government shares the half. The prepared amount for this supplement is ¥2.3T. At the end of 2009, 12.3M houses joined (23% of the whole nation). Total payment is expected to be reach the range of ¥1T covering 500 000 houses (¥78.3B for 65 000 houses in case of Hanshin-Awaji Megaquake in 1995). The maximum coverage option is set up to 30-50% of the fire insurance.

The following table 4 is showing damages to houses reported by the National Police Agency of Japan as of April 21 at 8 PM (20:00) JST.

Table 4: Damage to Houses due to earthquake, tsunami and fire

Prefecture/ Area	Property damages (unit of houses)					
	Total collapse	Half collapse	Partially damaged	Burn down	Inund. above floor level	Inund. below floor level
Hokkaido			**5**		**294**	**433**
Aomori	**272**	**970**	**54**		**14**	**12**
Iwate	**17,746**	**1,041**	**728**	**14**	**3**	**9**
Miyagi	**46,273**	**9,390**	**8,799**	**119**	**36**	**2,261**
Akita			**3**			
Yamagata	**37**	**80**				
Fukushima	**1,966**	**3,818**	**31,728**	**80**	**57**	**25**
Tokyo		**11**	**257**	**3**		
Ibaraki	**892**	**4,737**	**89,196**	**37**	**1,055**	**718**
Tochigi	**155**	**1,193**	**38,643**			
Gunma		**1**	**14,366**			
Saitama		**5**	**1800**	**1**		**1**
Chiba	**664**	**2,136**	**16,721**	**5**	**961**	**682**
Kanagawa			**8**			
Niigata			**9**			
Yamanashi						
Shizuoka			**4**			**7**
Mie					**2**	
Tokushima					**2**	**8**
Kochi					**6**	**10**
Total	**68,005**	**23,382**	**202,321**	**260**	**2,430**	**4,166**

The following table 5 is showing damages to infrastructures (roads, dikes, railways, etc.) as of April 21 at 8 PM (20:00) JST.

Table 5: Infrastructure damages and number of landslides

Prefecture/ Area	Infrastructure damages and landslides				
	Damaged roads	**Damaged bridges**	**Landslides**	**Break dikes**	**Damaged railways**
Hokkaido					
Aomori	2				
Iwate	30	4	3		
Miyagi	1,147	23	51	4	23
Akita	9				
Yamagata	21		29		
Fukushima	19	3	9		
Tokyo	13		3		
Ibaraki	307	41			
Tochigi	257		40		2
Gunma	7		4		
Saitama	160				
Chiba	1573		45		1
Gifu	1				
Total	**3,456**	**71**	**184**	**4**	**26**

3.5 Lowering criteria for heavy rain warnings or advisories in the earthquake affected area by Japan Meteorological Agency

As heavy rain seeping underground increases risk of sediment-related disasters such as debris flow and slope failure, the criteria for issue of the warning and advisory are based not only on the amount of rainfall but also on “soil water index”, an indicator of the amount of water in soil to represent the risk of sediment-related disasters. In the earthquake affected area, the risk of sediment disaster is higher than usual because the soil in these areas has been shaken and loosen.

Considering possible damages to soils by Earthquake and Tsunami on 11th March 2011 as well as the subsequent large earthquakes which occurred in Nagano and Shizuoka prefecture on 12th and 15th March in 2011 respectively, JMA has been tentatively operating by lowering the criteria of soil water indexes for its heavy rain warning/advisory for all municipalities (colored in yellow in the below Figure 7) where 5 + or greater of JMA seismic intensities were observed in those earthquakes.

Moreover, the Japan Meteorological Agency (JMA) tentatively changes the criteria for warnings and advisories of heavy rain and flooding in the affected areas in the 2011 off the Pacific coast Tohoku Earthquake and the following tsunami.

In the earthquake affected areas, the risk of flooding and inundation is expected to be higher than usual due to damages to embankments and drainage facilities caused by quakes and tsunami. As part of its disaster risk reduction schema, JMA tentatively lowers the criteria for warnings and advisories when such a massive natural disaster occurs. In this case, JMA decided to lower the criteria of the Runoff Index (RI) and rainfall amount used for the warnings and advisories of heavy rain and flooding in the affected areas (colored in the map below) for the time being. See Table 6 and figure 7&8 for the tentative criteria and the target area.

Table 6 Tentative criteria

Target Area	Warnings/ Advisories to change	Criteria	Percentage of provisional criteria to the norm
Red in map (Figure 8)	Flood	Rainfall amount	60%
		RI	70%
	Heavy rain (inundation)	Rainfall amount	60%
Yellow in map (Figure 8)	Flood	RI	70%

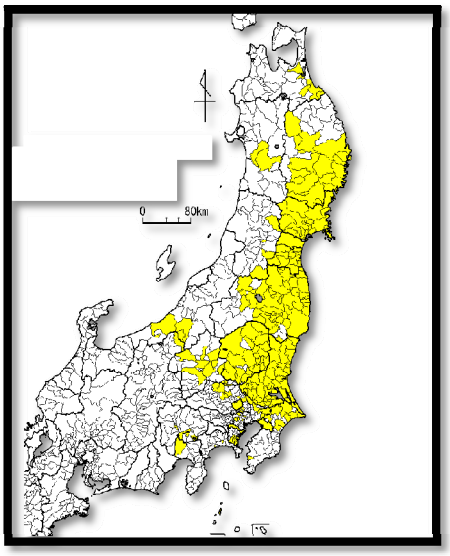


Figure 7 Target Area

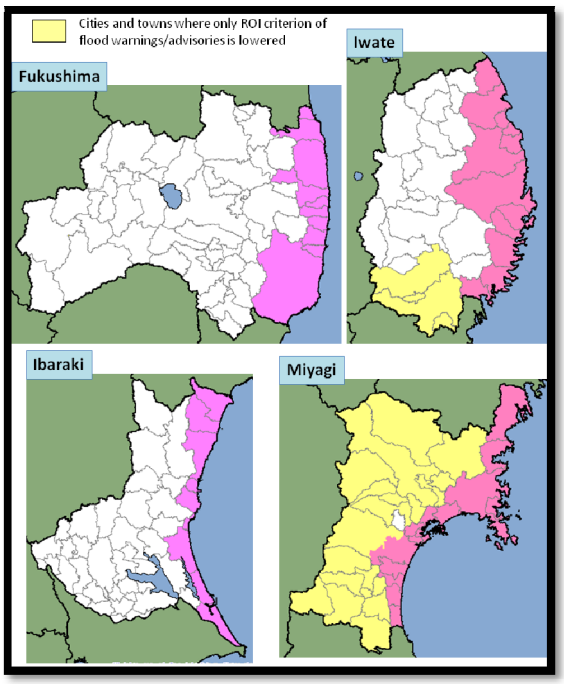
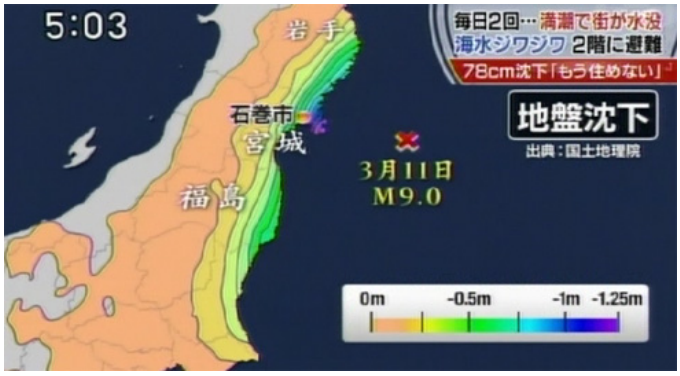


Figure 8 Target Areas for the tentative criteria in the table 6

3.6 Land Subsidence

The magnitude 9.0 earthquake that struck Japan caused land subsidence in large parts of Tohoku. In most areas, the ground has only dropped a few centimeters, making the change barely noticeable. However, according to a report from Japan National Geographical Survey Institute reported by Asahi Newspaper and TV (Figure 9), some coastal areas have sunk to below sea level, leaving them permanently flooded.



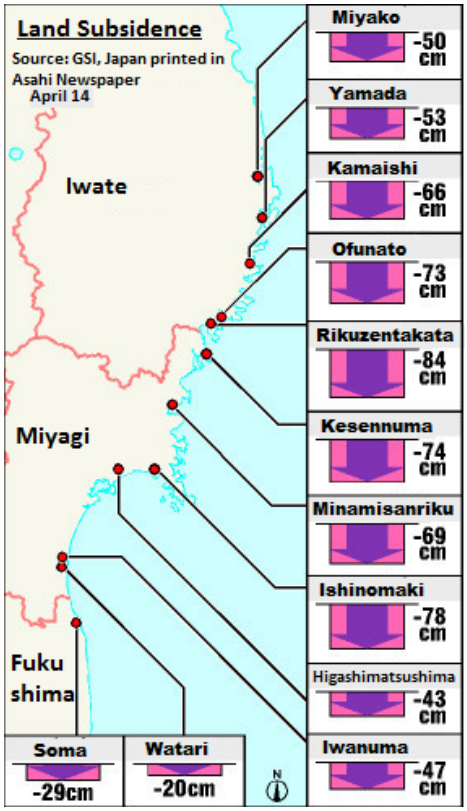


Figure 9 Land subsidence measured by GPS on April 14

The largest fall of 84 cm was observed in Rikuzentakata, Iwate Prefecture, followed by 78 cm in Ishinomaki, Miyagi Prefecture, said the institute that released the findings of its survey which used the global positioning system. A drop of 29 cm was also found in Soma, Fukushima Prefecture. The drops were caused by a counter balance of the sharp rise of the plate in the slip zone.

4. Some other memos

- 2011 Off Tohoku Coast Earthquake was overlooked as Pacific Ocean Plate was considered non-cohesive and to sink smooth. But it was found very cohesive and strong bounce back. (Kunihiko Shimazaki, chair of liaison committee for earthquake prediction, Nikkei on28 March)
- David Cyranoski, Japan faces up to failure of its earthquake preparations – System for forecasting, early warning and tsunami protection all fell short on 11 March. Nature 471, 556-557 (29 March 2011) http://www.nature.com/news/2011/110329/full/471556a.html
- Robert J. Geller, Shake-up time for Japanese seismology, Nature, doi:10.1038/nature10105 Published online13 April 2011
http://www.nature.com/nature/journal/vaop/ncurrent/full/nature10105.html
http://www.japantoday.com/category/national/view/tokyo-univ-professor-calls-on-japan-to-stop-predicting-quakes
- Some debates:
http://www.nature.com/nature/debates/earthquake/equake_frameset.html