Internet Journal of Society for Social Management Systems Vol.11 Issue 2 sms17-8209
ISSN: 2432-552X
ORIGINAL ARTICLE

Statistical Analysis of Tsunami Waste and the Treatment in the Great East Japan Earthquake

Wanglin Yan[1], Kaito Yokoyama[2] and Jinling Hua[3]

1 Faculty of Environment and Information Studies, Keio University
5322 Endo, Fujisawa City, Kanagawa, 252-0882, JAPAN

2 Graduate School of Media and Governance, Keio University
5322 Endo, Fujisawa City, Kanagawa, 252-0882, JAPAN

3 Research Institute of SFC, Keio University
5322 Endo, Fujisawa City, Kanagawa, 252-0882, JAPAN

* Email: yan@sfc.keio.ac.jp

Abstract: Speedy treatment of disaster waste is a prerequisite for smooth post-disaster recovery and reconstruction. However, it is difficult to estimate the quantity of disaster waste properly because of data unavailability and big uncertainties. The tsunami triggered by the Great East Japan Earthquake on 11 March 2011 produced as much as 25 million tons of waste in northeast Japan (Tohoku). This study scrutinized the governmental and professional reports on post-disaster waste treatment in Iwate and Miyagi Prefectures and inventoried the waste amount and composition, treatment processes. Statistical analyses were conducted between the tsunami debris and sediment with inundated area, built-up area, population, and collapsed houses. As results, we concluded that the tsunami debris was highly correlated with the heavily flooded built-up area with coefficients up to R^2=95 while the tsunami sediment was mainly influenced by lightly flooded areas. This conclusion limits to Japanese context where low story wooden houses dominate the devastated areas along rias coast.

Keywords: tsunami disaster waste, statistic analysis, Great East Japan Earthquake, built-up area

1. Introduction

Disasters of earthquakes, tsunamis, typhoons, floods and landslides decimate buildings, bridges and roads, and produce massive disaster waste. Brown & Milke (2010) highlighted eight key issues in disaster waste management: 1) waste management goals, 2) prioritization and timing, 3) environmental impact, 4) economics, 5) social factors, 6) organisational and coordination structures, 7) legislative issues, and 8) financial aspects/funding mechanisms. The solutions of these issues depend on type, magnitude, and geographical and social conditions of disasters. Asari et al (2013) argued the strategy for sorting and disposing disaster waste and stated the importance of estimating the quantity of disaster waste. Kobayashi summarized the problems in disaster waste treatment learned from the experience of Hanshin-Awaji Earthquake (UNEP, 1995), including 1) remove rubble and other waste on roads speedily, 2) consider the risk of treatment plants to be damaged and the treatment capacity to be reduced, 3) the immense quantity of wastes to be generated by demolition and dismantling of buildings. The information and knowledge is

Received: 2017.08.08 / Accepted: 2018.01.22

Internet Journal of Society for Social Management Systems Published Date: 2018.07.10

helpful for planning disaster waste treatment in emergency and recovery. Pre-disaster waste management has been also closed up in the conferences of Society for Social Systems Management, such as the paper published by Tajima et al. (2014).

Quantitative estimation of disaster waste has been reported by FEMA in 2007, USEPA in 2008, Japan (2009 and 2010). USEPA (2008) suggested that pre-disaster waste estimations are beneficial in both pre-disaster planning and post-disaster response. Quantifying the amount of waste in advance is a key in preparation for disaster waste treatment, not only in preparation for earthquake, but also climate extremes. In responding to climate change adaptation, for instance, the Office of Solid Waste and Emergency Response, EPA, recommended that "*Current waste management capacity, including interim capacity, may be insufficient to handle surges in necessary treatment and disposal of hazardous and municipal wastes, as well as mixed wastes generated from climate events*" (EPA, 2013).

The quantity of waste varies with type of disaster and geographic context of regions. Because of data unavailability, no one size fits all. Chen et al. (2007) correlated waste generated by four flooding events in Taiwan with three parameters: population density, total rainfall and flooded area. The significant non-linear model is constructive for predicting the volume of waste in future floods in Taiwan. Tabata et al. (2016) estimated the waste of domestic durables caused by typhoons in Japan. They created a universal mass per unit database for different types of waste and estimated the quantity of waste that could be generated from homes in regions predicted to be affected by the Nankai (southeast sea) Trough Earthquakes in West Japan (Tabata, Zhang, Yamanaka, & Tsai, 2016). Overall, these studies are context and disaster specific. In case of tsunami disaster, the damage could be context-specific to coastal topography, land use, and intensity of urban development.

The devastated tsunami triggered by the gigantic earthquake of Magnitude 9.0 in the offshore of the northeast Japan on March 11, 2011 heavily stroke the coastal municipalities of Prefectures in Tohoku region, and caused 15,894 deaths, 6,152 injured, and 2,562 missing persons. 228,863 people evacuated to either temporary houses or permanently relocated sites. According to the governmental report on 10 Feb 2014, totally 127,290 buildings were collapsed; a further 272,788 were "half collapsed"; and another 747,989 partially damaged. The earthquake and tsunami caused extensive and severe damages to social infrastructures of roads, railways, harbors and sea walls. A massive amount of disaster waste was generated to 25 million tons in which Miyagi Prefecture took the largest share by 68.2% and Iwate Prefecture was the second largest by 20%. By the end of March 2014, all of the disaster waste was processed by recycling, reusing and incinerating. Research questions on this paper are how the waste was processed and what were the driving factors for the generation of the massive disaster waste.

1.1 Objectives

This paper inventories the disaster waste in Iwate and Miyagi Prefectures of Tohoku Japan after the Great East Japan Earthquake, examines the variation of the quantity, composition and distribution of wastes in this region, and identifies

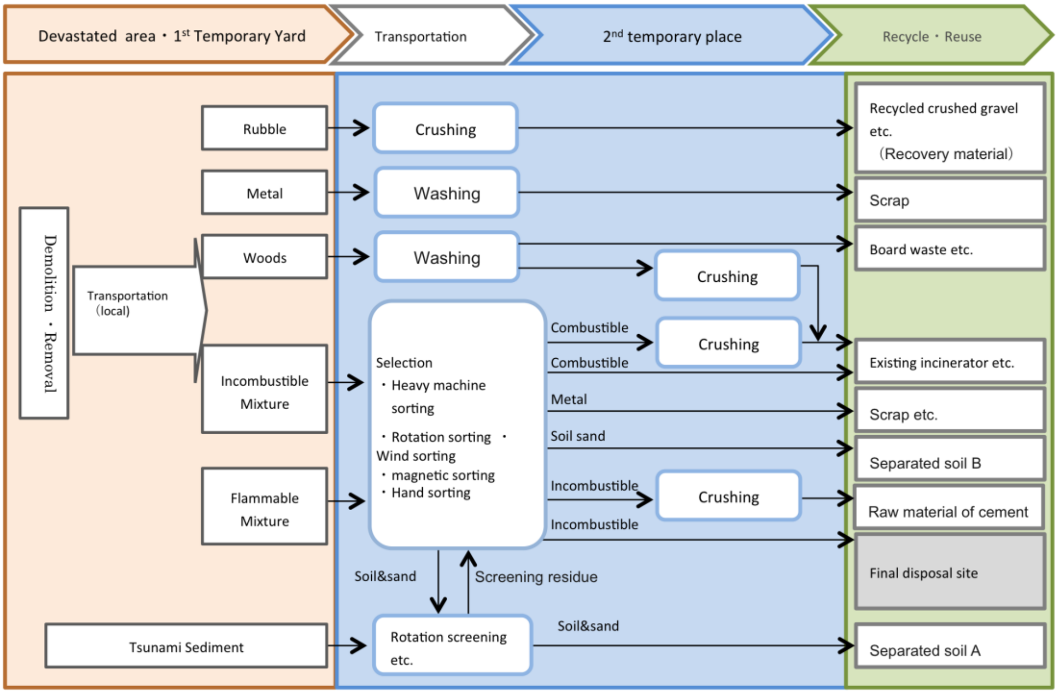


Fig.1 The general process of disaster waste treatment

Separated soil A: sediment & gravel reusable for construction.
Separated soil B: incombustible and reusable sediments.

the driving factors for the generation of disaster waste by the tsunami disaster. The empirical knowledge could be a reference for disaster preparation in other regions.

2. Research Method

2.1 Disaster Waster Treatment System in Tohoku Region

A municipality is responsible to collect, transport, treat and recycle the waste generated within its administrative area in Japan, according to the Waste Treatment Act. Each municipality treats waste individually in general while small ones are often grouped into a block operated by association. The municipalities along the northeast coastal region of Japan include cities, towns and villages where population ranges from millions to several thousands. The municipalities in Iwate and Miyagi Prefectures were grouped into 12 blocks from north to south. Daily waste of each municipality was transported and treated at the facilities of cities or the blocks routinely.

Local governments should also cover the costs for waste treatment. In heavily devastated or specially needed condition, however, national government will provide financial support, according to Article 22 of the law. In the wake of the Great East Japan Earthquake, municipalities have played a key role in post-disaster waste treatment. To cope with the massive amount of tsunami waste, Japanese government also made a special law, by which the central government set up a special fund to cover the costs for disaster waste treatment up to 95%. Another 5% was prepared by the special local allocation tax for post-disaster reconstruction.

The massive amount of disaster waste exceeded the capacity of waste treatment facilities for daily garbage. Iwate and Miyagi prefectures had constructed 10 temporal incinerators in order to absorb the overflow and accomplished the disaster waste treatment in three years. Municipalities and prefectures have worked collaboratively. In Iwate and Miyagi, municipalities and prefectures have undertaken the waste treatment by 50% each other.

The process of disaster waste treatment in post-3.11 was illustrated in Fig.1. Disaster wastes were collected by tsunami debris and tsunami sediment separately. The former was the rubble of collapsed houses and buildings; the later was the remained soils after tsunami. Both type of the waste were collected to the first temporary garbage yard in order to clean road and land for recovery.

The terms of waste and debris are used differently in literature (Brown, Milke, & Seville, 2011). In general, debris refers to largely inert building and vegetative materials generated by disaster, and waste refers to the entire waste matrix, including post-disaster municipal waste. Tsunami produces a massive amount of sediment in flooded plain. We use waste to refer all of the garbage, debris to the content of waste including woods, rubble and metal, etc., and sediment to tsunami remains.

Debris was sorted at the 1st temporary storage yard to concrete rubble, metal, vegetative parts, incombustible and flammable mixture. The sorted debris is transported to the 2nd temporary storage yard where rubbles is raptured; metal and vegetative poles are washed; incombustible and flammable mixtures are sorted manually or machinery further into flammable, metal, soil and gravel, incombustible materials and incombustible materials. Finally, unrecyclable vegetative poles, flammable mixture are transported to incinerators; Rubbles are raptured to gravel for basement of construction; metals are cleaned and scraped; vegetative poles are recycled as plywood etc. Soil and gravel from debris and sediment are sorted and recycled as soil A and soil B, as noted in Fig.1. Temporary incinerators, 4 in Iwate and 12 in Miyagi were built to incinerate flammable waste. In the devastated regions, recycle rate reached to 90%. Incombustible waste was transported to waste disposal sites.

2.2 Datasets for identifying regional characteristics

We collected the information relevant to the disaster waste treatment after 3.11 from various sources, and reconfirmed with municipal staff for ensuring the reliability of data inventory when necessary. Here are the major items of the inventories. Sources of each item were given at the end of the paper as notes.

1) Amount of tsunami waste: debris (including vegetative trash, flammable) and sediment, mixture, incombustible mixture, rubble, metal trash, fishing tools and net, others, by the Ministry of Land, Infrastructure, Transportation and Tourism (MLIT).
2) Inundated households and population: number of residents whose houses were flooded or damaged, by National Fire Department.
3) Inundated houses: collapsed and floated away, half collapsed, partially (first floor) inundated, by Fire and Disaster Management Agency
4) Inundated land: inundation depth, by MLIT.
5) Treatment system: treatment ways (incinerated, recycled), treatment sector (prefecture, municipality), cost (total budget, governmental subsidies), and time cost (preparation,

construction, processing, restoration), by Iwate and Miyagi Prefecture.

6) Inundated area. Spatial division separated the inundated area into four zones: zone A-houses were completely collapsed or floated away; zone B-houses flooded up to first floor ceiling and collapsed heavily; zone C-partially flooded and collapsed; zone D-within a flooded area but no damage, by MLIT.
7) Facilities: existing waste treatment facilities, temporary facilities, by Iwate and Miyagi Prefecture.
8) Incinerators and operating period, Iwate and Miyagi Prefecture.
9) Spatial data infrastructure and coastline from National Geographic Institute, MLIT.

3. Results

3.1 Variation of disaster waste treatment

Collected from local governmental and enterprise reports we created the inventory of disaster waste treatment in Iwate and Miyagi Prefectures in Table 1, 2, 3 and 4. As shown in Table 1, Iwate Prefecture had 4,220,000 tons of tsunami debris and 1,600,000 tons of tsunami sediments while Miyagi Prefecture had 11,100,000 tons and 7,540,000 tons respectively. These two prefectures occupied 68% of the waste from this disaster. Five cities, including Rikuzentakada, Kesennuma, Ishinomaki, Higashimatsushima and Sendai, are main contributors, which produced more than one million tons of debris. Meanwhile, Higashimatsushima and Sendai had collected much more than one million tons of sediments. Large deviation exists among 27 municipalities. Ishinomaki City and Sendai City were the two with the largest inundated area. Higashimatsushima City had massive waste, debris and sediment while the inundated population was less. Disaster debris occupied 72% in Iwate and 61% in Miyagi although the percentage varies from the lowest 33% (Higashimatsushima City) to the highest 100% (several village and towns). Some cities and towns had more sediments than debris.

3.2 Debris composition

The composition of disaster waste is summarized in Table 2 by municipality. Because of the data unavailability, several municipalities were aggregated by block, including Ishinomaki Block and Miyagi Eastern Block. The composition of debris may reflect the regional structure. Generally, Miyagi had much wooden and flammable debris while Iwate had much incombustible, rubble and metal. By percentage, rubble took the share over 50% in half of the municipalities while the percentage ranges from 34% to 80%. Fishing net in Miyagi was zero in Table 2 because it was transported to the collaborative municipalities outside of the prefecture.

The waste and debris per hectare, per person, the total cost, unit cost as well as treatment system were given in Table 3.

The remarkable variation among these indicators signifies the diversity of urban forms and structures, and the complex mechanism of the disaster waste generation. The budget deployed for disaster waste treatment reached to totally 974.4 billions, 271.5 billions in Iwate and 702.9 billons in Miyagi respectively. The average costs per ton accounted to 47,000 yen in Iwate and 37,000 yen in Miyagi. Shiogama sits at the top of the treatment costs by 64,000 per ton mostly because of the rent for private land for temporary yards. Regarding the treatment systems, some cities operated independently while others required for support from the prefecture. Higashimatsushima was the cheapest by 18,000 yen per ton, probably the effect of early citizen participation, according our interview. No clear clues link the treatment costs with treatment systems, recycle rate and incinerated rate.

4. Discussions

4.1 Driving Factors of disaster waste

The variation of waste quantity among municipalities in Table 1 is observable. To examine the driving factors on the generation of disaster waste, we conducted single correlations of debris

Table 1 disaster waste and the way of treatment after 3.11

Prefecture	Municipality	Total Waste (t)	Debris (t)	Sediment (t)	Share of Debris (%)	Flooded Area (ha)	Flooded Population (pers.)
Iwate	1 Iwate Pref total	5,836,991	4,228,100	1,608,891	72.44	5,685	107,503
Iwate	2 Hirono T	20,071	17,254	2,817	85.96	176	2,733
Iwate	3 Kuji C	90,198	76,089	14,109	84.36	368	7,171
Iwate	4 Noda V	167,336	120,906	46,430	72.25	247	3,177
Iwate	5 Pudai V	14,247	14,247	0	100.00	66	1,115
Iwate	6 Tanohata V	55,483	36,674	18,809	66.10	138	1,582
Iwate	7 Iwaizumi V	64,982	30,834	34,148	47.45	100	1,137
Iwate	8 Miyako C	802,105	601,478	200,627	74.99	812	18,378
Iwate	9 Yamada T	482,218	423,151	59,067	87.75	493	11,418
Iwate	10 Ohtsuchi T	659,304	452,835	206,469	68.68	375	11,915
Iwate	11 Kamaishi C	945,381	753,101	192,280	79.66	777	13,164
Iwate	12 Ohunato C	853,110	623,567	229,543	73.09	813	19,073
Iwate	13 Rikuzentakada C	1,682,556	1,077,964	604,592	64.07	1,320	16,640
Miyagi	14 Kesennuma C	1,977,000	1,138,000	839,000	57.56	1,732	40,331
Miyagi	15 Minamisanriku C	723,000	556,000	167,000	76.90	1,142	14,389
Miyagi	16 Ishinomaki C	4,325,000	3,589,000	736,000	82.98	5,654	112,276
Miyagi	17 Higashimatsushima C	3,259,000	1,098,000	2,161,000	33.69	3,419	34,014
Miyagi	18 Onagawa T	577,000	577,000	0	100.00	329	8,048
Miyagi	19 Matsushima T	65,000	63,000	2,000	96.92	167	4,053
Miyagi	20 Rifu T	19,000	19,000	0	100.00	13	542
Miyagi	21 Sendai C	2,717,000	1,362,000	1,355,000	50.13	4,720	29,962
Miyagi	22 Tagajo C	350,000	242,000	108,000	69.14	596	17,144
Miyagi	23 Shiogama C	249,000	239,000	10,000	95.98	410	18,718
Miyagi	24 Shichigahama T	532,000	228,000	304,000	42.86	483	9,149
Miyagi	25 Natori C	963,000	741,000	222,000	76.95	2,550	12,155
Miyagi	26 Iwanuma C	627,000	473,000	154,000	75.44	2,550	8,051
Miyagi	27 Watari T	856,000	495,000	361,000	57.83	3,089	14,080
Miyagi	28 Yamamoto T	1,640,000	784,000	856,000	47.80	2,379	8,990
Miyagi	29 Miyagi Pref total	18,879,000	11,604,000	7,275,000	61.47	29,233	331,902

Internet Journal of Society for Social Management Systems Vol.11 Issue 2 sms17-8209
ISSN: 2432-552X

Table 2 Composition of Disaster Waste in Tohoku Japan

Prefecture/Municipality		Debris	Wood	Flammable	Incombustible	Rubble	Metal	Fishing Net
Prefecture	Munici. or block	(t)	%	%	%	%	%	%
Iwate	1 Iwate Pref total	4,228,099	1.74	13.97	25.88	52.05	4.32	0.60
Iwate	2 Hirono T	17,253	4.95	7.38	1.90	80.90	1.37	3.40
Iwate	3 Kuji C	76,089	5.87	6.67	39.11	45.79	1.75	0.62
Iwate	4 Noda V	120,907	2.89	10.05	47.17	36.70	2.73	0.32
Iwate	5 Pudai V	14,246	16.89	4.35	13.18	58.30	2.46	3.47
Iwate	6 Tanohata V	36,675	4.43	7.73	19.38	60.10	6.32	1.83
Iwate	7 Iwaizumi V	30,833	1.28	21.18	38.96	34.27	3.65	0.44
Iwate	8 Miyako C	601,478	1.59	17.10	34.14	38.71	3.04	0.69
Iwate	9 Yamada T	423,150	2.15	8.86	40.49	42.14	4.76	1.17
Iwate	10 Ohtsuchi T	452,835	0.35	11.82	24.41	56.60	6.28	0.40
Iwate	11 Kamaishi C	753,102	1.63	11.47	9.56	71.85	4.82	0.43
Iwate	12 Ohunato C	623,567	1.28	25.50	20.20	43.02	5.47	0.81
Iwate	13 Rikuzentakada C	1,077,964	1.82	11.39	27.91	54.71	3.42	0.30
Miyagi	14 Kesennuma C	984,615	9.99	26.17	1.97	51.43	5.65	0.00
Miyagi	15 Minamisanriku C	551,582	5.25	32.62	2.02	56.09	3.07	0.00
Miyagi	Ishinomaki block	4,998,063	11.10	1.57	23.07	56.23	2.84	0.00
Miyagi	16 Ishinomaki C							
Miyagi	17 H. Matsushima C							
Miyagi	18 Onagawa T							
Miyagi	19 Matsushima T	61,000	40.98	8.20	0.00	45.90	1.64	0.00
Miyagi	20 Rifu T	18,000	16.67	5.56	11.11	44.44	0.00	0.00
Miyagi	21 Sendai C	1,362,000	7.27	19.24	8.59	57.05	5.43	0.00
Miyagi	Miyagi E block	698,834	7.76	16.56	14.54	54.55	2.29	0.00
Miyagi	22 Tagajo C							
Miyagi	23 Shiogama C							
Miyagi	24 Shichigahama T							
Miyagi	25 Natori C	739,376	1.52	49.68	7.64	39.26	1.44	0.00
Miyagi	26 Iwanuma C	463,578	6.06	4.25	58.86	29.49	1.19	0.00
Miyagi	27 Watari T	475,537	9.22	2.89	54.79	29.35	3.57	0.00
Miyagi	28 Yamamoto T	748,929	8.35	9.91	47.84	30.60	2.24	0.00
Miyagi	29 Miyagi Pref total	11,101,514	7.49	21.81	22.83	42.79	2.94	0.00

quantity with inundated area, population and collapsed houses. We also checked the amount of sediment to that of debris among 27 municipalities. As shown in Fig.2, the amount of debris has strong correlation with flooded area, flooded population by R^2=0.78 and 0.73 respectively. The correlation between waste amount and the number of fully and half collapsed houses are lowed by Sendai City (Fig.2c). Similar pattern happens in the ratio of sediment to debris, by Ishinomaki City in this case (Fig.2d). The share of sediment is larger than debris in some municipalities. This signifies the impact of urban structure and geomorphology of coastal regions. For instance, the sample in Fig.2c with largest collapsed houses is Sendai City located in large flood plain. The lowest ratio of sediment to debris in Fig.2d is Ishinomaki City, a populous city along coast with 147 thousands of population. The highest ratio of sediment to debris is observed in Higashimatsushima, a combination of hilly topography and flat plain in Sanriku rias coastal region. Meanwhile, Table 3 shows big differences in debris and sediment by person and hectare. Here no statistical correlation is observable.

Table 3 Statistics of disaster waste and treatment

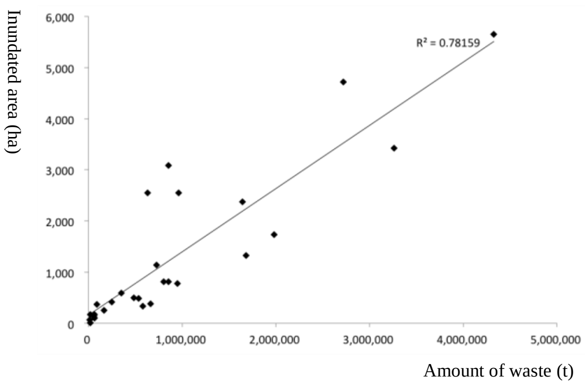
Prefecture/ Municipality	Debris (t/ha)	Debris (t/pers.)	Sediment (t/ha)	Sediment (t/pers.)	Total cost (1000 yen)	Cost per ton (1000 yen/t)	Treatment system
1 Iwate Prefecture	743.7	39.3	283.0	15.0	271,547,147	47	
2 Hirono T	98.0	6.3	16.0	1.0	844,537	42	City only
3 Kuji C	206.8	10.6	38.3	2.0	4,469,310	50	City only
4 Noda V	489.5	38.1	188.0	14.6	9,202,473	55	Prefecture
5 Pudai V	215.9	12.8	0.0	0.0	535,119	38	City only
6 Tanohata V	265.8	23.2	136.3	11.9	2,341,408	42	Prefecture
7 Iwaizumi V	308.3	27.1	341.5	30.0	2,117,995	33	Prefecture
8 Miyako C	740.7	32.7	247.1	10.9	37,216,685	46	Prefecture
9 Yamada T	858.3	37.1	119.8	5.2	21,618,869	45	Prefecture
10 Ohtsuchi T	1,207.6	38.0	550.6	17.3	24,503,507	37	Prefecture
11 Kamaishi C	969.2	57.2	247.5	14.6	40,531,568	43	City only
12 Ohunato C	767.0	32.7	282.3	12.0	48,517,622	57	City only
13 Rikuzentakada C	816.6	64.8	458.0	36.3	79,648,054	47	City only
14 Kesennuma C	657.0	28.2	484.4	20.8	114,600,603	58	Both
15 Minamisanriku C	486.9	38.6	146.2	11.6	33,125,715	46	Both
16 Ishinomaki C	634.8	32.0	130.2	6.6	194,715,444	45	Both
17 Higashimatsushima C	321.1	32.3	632.1	63.5	58,470,236	18	Both
18 Onagawa T	1,753.8	71.7	0.0	0.0	17,801,382	31	Both
19 Matsushima T	377.2	15.5	12.0	0.5	2,137,366	33	City only
20 Rifu T	1,461.5	35.1	0.0	0.0	466,274	25	City only
21 Sendai C	288.6	45.5	287.1	45.2	84,108,031	31	City only
22 Tagajo C	406.0	14.1	181.2	6.3	15,248,793	44	Both
23 Shiogama C	582.9	12.8	24.4	0.5	15,938,136	64	Both
24 Shichigahama T	472.0	24.9	629.4	33.2	16,688,403	31	Both
25 Natori C	290.6	61.0	87.1	18.3	31,839,857	33	Both
26 Iwanuma C	185.5	58.8	60.4	19.1	25,879,508	41	Both
27 Watari T	160.2	35.2	116.9	25.6	47,979,247	56	Both
28 Yamamoto T	329.6	87.2	359.8	95.2	43,888,314	27	Prefecture
29 Miyagi Prefecture	396.9	35.0	248.9	21.9	702,887,309	37	

4.2 Influence of geographic and demographic conditions

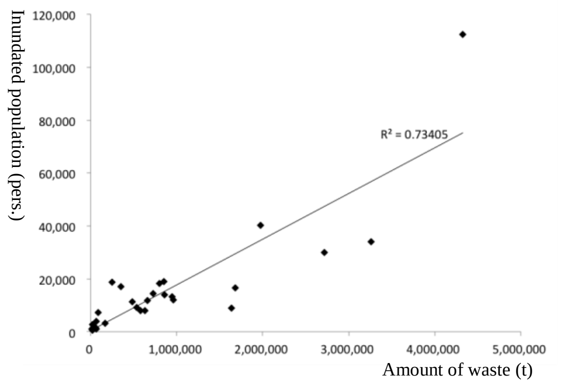
As mentioned above, the relationship of debris with collapsed houses implies the contribution of urban built-up area while the frustration of sediment/debris ratio may reflect the difference of geographic and demographic conditions. Buildings along the Sanriku rias coast were heavily damaged than buildings in the flood plain of Sendai (Suppasri et al., 2013). Geophysical condition of devastated area, from flood plain to rias coast is the key factor of inundation height (Mori, Takahashi, Yasuda, & Yanagisawa, 2011). MLIT has reported the inundated areas by four types of zones: Zone A, B, C and D according to the intensity of the collapsed houses. Table 4 shows the hectares of the zones by municipality.

To examine the dominant factors in the generation of debris and sediment, we conducted multiple regressions by taking the quantity of total waste, debris and sediment as the dependent variable respectively, the flooded area of each zone as the independent variables. The results of the statistical null hypothesis tests are shown in Table 5.

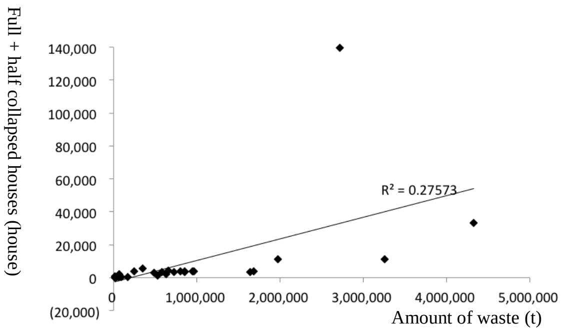
The regressions interpret the factors behind the variations of debris and sediment quantities in Table 1, 2, 3 and 4. The quantity of total waste is significantly correlated to the area of Zone A and C in R^2=0.862. The amount of debris is significant with the area of Zone A and C in R^2=0.951. The quantity of sediment is significant with Zone C only in R^2=0.677. This signifies that the densely built-up area, fully collapsed/floated-away houses, were the dominant factors of debris. The wide inundated



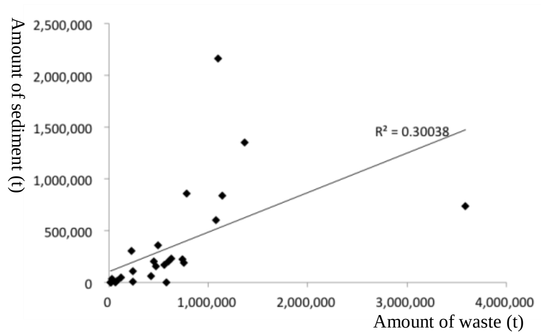
a. Correlation between waste amount and flooded area



b. Correlation between waste amount and flooded population



c. Correlation between waste and full+half collapsed houses



d. Correlation between debris and sediment

Fig.2 Single correlations in amount of waste, debris and sediment with flooded area, population and collapsed houses land received much sediment. The total quantity of tsunami waste must be an integration of debris and sediment. It is not clear why half collapsed houses did not contribute to debris significantly in statistics.

5. Conclusions

Japanese government had made great efforts on the disaster waste treatment after the Great East Japan Earthquake. The total quantity of the disaster waste in Iwate and Miyagi prefectures has exceeded to 23 million tons, almost as double as the estimation before the disaster. Because of the limitation on the sample number, this analysis does not intend to give a general regression mode. Nevertheless, some trends are observable from the inventories. The variation between municipalities is remarkable. Key factors are the density of flooded buildings, the extent of built-up area and geomorphology of the coast. As the results of statistical regressions, dense cities and towns along the valleys of rias coast produced much debris and rubble per unit area while villages with open land, and few buildings received much sediment. A huge amount of sediment in tsunami disaster should be considered in pre-disaster estimation. With the established system, the massive tsunami debris and

Table 4 Spatiality of flooded areas and damages to houses

Munici-pality	Zone A (ha)	Zone B (ha)	Zone C (ha)	Zone D (ha)	Collapse of houses (house)			
					Fully/floated	Half	Partially	Total
1	2,739	492	2,450	4	19,360	4,872	7,962	32,194
2	23	3	150	0	10	16	39	65
3	40	61	267	0	65	213	338	616
4	51	21	175	0	311	168	36	515
5	8	1	57	0	0	0	0	0
6	25	2	111	0	225	45	11	281
7	13	5	82	0	177	23	8	208
8	497	112	203	0	2,677	1,328	444	4,449
9	352	44	97	0	2,762	405	202	3,369
10	290	42	39	4	3,579	588	208	4,375
11	436	86	255	0	2,957	699	1,048	4,704
12	561	96	156	0	2,791	1,147	1,644	5,582
13	443	19	858	0	3,806	240	3,984	8,030
14	819	136	778	0	8,483	2,571	4,761	15,815
15	445	11	686	0	3,143	178	1,204	4,525
16	2,018	864	2,774	0	20,039	13,047	19,948	53,034
17	412	604	2,357	46	5,518	5,559	3,504	14,581
18	236	17	76	0	2,924	349	661	3,934
19	0	27	125	14	221	1,785	1,561	3,567
20	0	8	5	0	56	901	3,564	4,521
21	725	610	3,320	65	30,034	109,609	116,046	255,689
22	161	315	84	35	1,746	3,730	6,162	11,638
23	33	230	147	0	672	3,278	6,993	10,943
24	116	43	307	17	674	650	2,605	3,929
25	183	135	2,197	35	2,801	1,129	10,061	13,991
26	378	408	1,763	0	736	1,606	3,086	5,428
27	275	177	2,637	0	2,389	1,150	2,048	5,587
28	324	80	1,974	0	2,217	1,085	1,138	4,440
29	6,125	3,665	19,230	212	81,653	146,627	183,342	411,622

Data source for Zone A, B, C and D: Ministry of Land, Infrastructure, Transportation and Tourism (MLIT). https://www.mlit.go.jp/common/000162533.pdf

Table 5 Significant level of Multiple regressions of disaster waste, debris, rubble with inundated areas

Variable	Waste (t)			Debris (t)			Sediment (t)		
	Coefficient	P-level	Rejected	Coefficient	P-level	Rejected	Coefficient	P-level	Rejected
R^2		0.862			0.951			0.536	
Model		0.000			0.000			0.000	
Intercept	40,484	0.718		-7153.6	0.870		47,638.0	0.618	
Zone A (ha)	1417.1	0.000	*	1474.0	0.000	*	-63.0	0.802	
Zone B (ha)	896.5	0.197		166.1	0.545		733.3	0.214	
Zone C (ha)	338.4	0.010	*	100.6	0.040	*	235.6	0.030	*

Note: sample number=27.

sediment were mostly recycled and reused. However, The costs to process the waste was expensive too, 40 thousand yen per ton in average and totally 1000 billion yen in Iwate and Miyagi Prefectures. Reducing potential waste in regions prone to disasters should be considered in planning. The conclusions limit to Japanese context specific to the rias costal region. We could not identify the driving factors of waste composition because of the complexity of tsunami and unavailability of house structures.

Acknowledgements

This paper was the culmination of the project “Policy assessment for the sustainable disaster waste treatment in consideration of social risk to the gigantic earthquake”, the Ministry of Environment, Japan (No. 3K153008). We are grateful to the help of Higashimatsushima City, Natori City and many other municipalities for accepting our inquires and providing relevant information.

Data sources

1) Total waste debris and sediment
http://tohoku.env.go.jp/files/pdf/2014/0901bb.pdf (last access: 2016/09)
2) Total cost. Board of Audit of Japan,
http://report.jbaudit.go.jp/org/h25/2013-h25-1124-0.htm (last access: 2016/10/03)
3) Composition of Disaster Waste
Iwate:
http://tohoku.env.go.jp/files/pdf/2014/0901bb.pdf
Miyagi:
https://www.pref.miyagi.jp/uploaded/attachment/269961.pdf
4) Inundated area
Ministy of land, Infrastructure and Transport,
http://www.mlit.go.jp/common/000162533.pdf
(last access: 2017/01/08)
5) Inundated population
Iwate:
http://www.stat.go.jp/info/shinsai/pdf/sinsui03.pdf (last access: 2016/11/04)
Miyagi:
http://www.stat.go.jp/info/shinsai/pdf/sinsui04.pdf (last access: 2016/11/04)
6) Inundated house
Fire and Disaster Management Agency,
http://www.fdma.go.jp/bn/higaihou/pdf/jishin/150.pdf (last access: 2016/11/04)

References

1) Asari, M., Sakai, S. ichi, Yoshioka, T., Tojo, Y., Tasaki, T., Takigami, H., & Watanabe, K. (2013). Strategy for separation and treatment of disaster waste: A manual for earthquake and tsunami disaster waste management in Japan. *Journal of Material Cycles and Waste Management*, *15*(3), 290–299.
2) Brown, C., & Milke, M. (2010). Planning for Disaster Debris Management.
3) Brown, C., Milke, M., & Seville, E. (2011). Disaster waste management: A review article. *Waste Management*, *31*(6), 1085–1098.
4) Chen, J. R., Tsai, H. Y., Hsu, P. C., & Shen, C. C. (2007). Estimation of waste generation from floods. Waste Management, 27(12), 1717–1724.
5) EPA. (2013). *Office of Solid Waste and Emergency Response Climate Change Adaptation Implementation Plan*.
6) FEMA. (2007). Public assistance. Debris management guide. Federal Emergency Management Agency, (July), 260. Retrieved from www.fema.gov/pdf/government/grant/pa/demagde.pdf%0Ahttp://www.fema.gov/government/grant/pa/demagde.shtm
7) Mori, N., Takahashi, T., Yasuda, T., & Yanagisawa, H. (2011). Survey of 2011 Tohoku earthquake tsunami inundation and run-up. *Geophysical Research Letters*, *38*(18), 6–11.
8) Suppasri, A., Mas, E., Charvet, I., Gunasekera, R., Imai, K., Fukutani, Y., … Imamura, F. (2013). Building damage characteristics based on surveyed data and fragility curves of the 2011 Great East Japan tsunami. *Natural Hazards*, *66*(2), 319–341.
9) Tabata, T., Zhang, O., Yamanaka, Y., & Tsai, P. (2016). Estimating potential disaster waste generation for pre-disaster waste management. *Clean Technologies and Environmental Policy*, *18*(6), 1735–1744.
10) Tajima, R., Hirayama, N., & Osako, M. (2014). Theory and practice of pre-disaster planning for disaster waste management. *Society for Social Management Systems Internet Journal*, *12*, 13. Retrieved from http://hdl.handle.net/10173/1239
11) USEPA. (2008). Planning for Natural Disaster, (March), 1–94. Retrieved from http://www.epa.gov/wastes/conserve/imr/cdm/pubs/pndd.pdf%5Cn
12) UNEP. (1995). Proceedings of earthquake waste symposium. In Proceedings of earthquake waste symposium, Osaka, 12-13 June 1995. (pp.1–146). UNEP International environmental Technology Centre.