Earthquake disaster waste management reviews: Prediction, treatment, recycling, and prevention

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(Citation)
International Journal of Disaster Risk Reduction,36:101119

(Issue Date)
2019-05

(Resource Type)
journal article

(Version)
Accepted Manuscript

Title

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Abstract

Rapid removal and treatment of waste generated during earthquakes is essential for the rapid recovery and reconstruction of the affected area. However, the environmental burden of disaster waste management efforts should not be overlooked even in disaster situations.

Disaster waste management should be systematized as an integrated system wherein disaster waste management processes flow from generation to treatment. Life cycle thinking effectively makes sense of each stage of disaster waste management. Disaster waste prevention also might effectively reduce the environmental burden. This study reviews research trends in the management of disaster waste from the perspectives of the estimation of potential disaster waste, systematic evaluations of disaster waste management, and the necessity of addressing the material aspects of disaster waste prevention. In addition, the importance of measures for the prevention of disaster waste is examined in its social and cultural aspects, including such interventions as a change in residents' lifestyle in regard to the possession of consumer durables.

Keywords

Disaster waste management; life cycle thinking; waste prevention; disaster waste prediction; disaster prevention lifestyle

Abbreviations

GIS; Geographic Information System

JMA; Japan Meteorological Agency

LCA; Life cycle assessment

LCC; Life cycle cost

1. Introduction

Earthquakes are often complex disasters with associated earthquake-induced vibrations, landslides, tsunamis, and so on. They cause severe damage to life and property, and as a result, buildings, infrastructure, and consumer durables are converted into disaster waste. Japan has the third largest economy in the world, and it is rare for such a developed country to experience earthquakes so frequently. For example, the 1995 Great Hanshin-Awaji Earthquake caused approximately 6 400 deaths, destroyed approximately 256 000 dwellings, and produced approximately 20 million tons of disaster waste [1]. The Great East Japan Earthquake caused approximately 16 000 deaths, destroyed approximately 1.1 million dwellings, and produced approximately 28 million tons of disaster waste [2]. The centrepiece of recovery and reconstruction of an earthquake-affected area is the quick removal and treatment of waste. The Cabinet Office of the Japan [3] announced a basic plan for disaster management in 2015, indicating that disaster waste should be recycled if possible. This is a fundamental principle of disaster waste treatment because such waste originally consisted of natural resources, and recycling it contributes to the circular economy. On this principle, 81% of disaster waste was recycled after the 2011 Great East Japan Earthquake [4]. The Japanese government has also prepared for greater resilience in future earthquakes, especially predictions of the Nankai Trough and the Tokyo Near-field Earthquakes. The former will affect mainly western Japan, including the Greater Osaka area, with a predicted generation of approximately 350 million tons of waste [5]. The latter will mainly affect the Greater Tokyo area with waste expected in excess of 110 million tons [5]. In light of such predictions, the Japanese government and local municipalities have been developing strategies to manage the waste. In addition, many other studies of earthquakes have been conducted in Japan.

The environmental burden caused by the disposal and treatment of this waste is incalculable [6, 7]. He and Zhuang [8] indicate that environmental and economic losses from a disaster are determined not only by the response to the disaster but also by prevention measures taken beforehand. This applies ably to disaster waste management. The United States EPA [9] identifies the following considerations as necessary to any preliminary plan for better waste management: the amount and type of potential waste, whether municipal solid waste treatment facilities can handle disaster waste, the location and treatment capacity of these facilities, the location and capacity of temporary storage sites, and the means of recycling. The environmentally and economically sound management of disaster waste is achieved through careful planning by decision makers before the earthquake. An integrated approach using life cycle thinking, represented by LCA and LCC, should be appropriate to the decision making methods involved in management planning because these methods systematically evaluate environmental burden and cost of waste removal and treatment [10]. Life cycle thinking begins by estimating the amount and type of waste that might potentially be generated by a natural disaster. To arrive at such an estimation, it is necessary to simulate a disaster scenario.

Disaster waste prevention no less important a perspective. For example, the construction and renovation of flood-prevention facilities [11, 12] and earthquake-resistant buildings [13, 14], the seismic reinforcement of consumer durables [15, 16], and the relocation of residences to higher elevations [17] are all being implemented or are considered a part of disaster prevention and reduction. With a simple change of perspective, these measures reveal themselves as means for preventing the generation of waste by reducing potential damage. Disaster waste starts as a stock as known as commodity that exists originally within a particular region. Reducing the loss of stock contributes to the rapid recovery and reconstruction of an affected area. This viewpoint is indispensable for increasing regional resilience and the return to day-to-day life at an earlier stage for those persons affected. Disaster waste prevention also reduces the environmental burden. Within a circular economy, waste prevention is the highest priority of waste management, a concept that should also be considered in the management of disaster waste. Any savings of cost due to disaster waste prevention can be applied to restoration and reconstruction. Despite this, disaster waste prevention has not attracted much attention, having to compete with the high priority given to recycling in Japanese governmental policy.

In Japan, research into disaster waste management increased after a considerable accumulation of data derived from devastating major earthquakes. The research done by academics has contributed to the preparation of a waste management plan by the national and local governments. Today, many Japanese researchers continue striving to strengthen resilience in order to prepare for major earthquakes of the future, basing their efforts on others of the past. Through financial support from Japan Ministry of Environment, the authors have also developed methods for evaluating disaster waste management using life cycle thinking[1]. This paper aims to review research trends in disaster waste management, focusing on earthquakes mainly in Japan. This paper also discusses the necessity of disaster waste prevention by reviewing the results of our case study of seismic retrofitting of flood-prevention facilities. The layout of Chapters 2 through 4 is as follows: Chapter 2 reviews research relevant to the estimation of potential disaster waste generation as a key for disaster waste management. This chapter also reviews decisions on the creation of policy and construction of disaster waste management. Chapter 3 reviews the environmental and economic effects

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[1] See references [6,7], [10], [13], [17], [39], [42], [65-67].

of disaster waste prevention, focusing on the authors' research findings. Chapter 4 describes the prospects for promoting disaster waste prevention.

2. Literature review

2.1. Potential disaster waste generation

Representative methods for estimating potential disaster waste generation take the total number of completely or partly destroyed dwellings, sorted by type of damage, and multiply it by the material intensity coefficients of disaster waste per dwelling [18, 19, 20]. There are two methods for the creation of material intensity coefficients: one is based on the actual amount of disaster waste in past earthquakes, and the other is based on existent stock in a given area. Table 1 shows examples of the two methods of creating material intensity coefficients. Representative research, using the former method, involves two cases: one, identifying the weight and capacity of dismantled waste due to the collapse of dwellings in the 1995 Great Hanshin-Awaji Earthquake [1, 21], and two, assessing the weight of material and structures damaged by the earthquake and tsunami through the survey of areas affected by the 2011 Great East Japan Earthquake [22, 23]. Actual performance regarding the generation and treatment of disaster waste in past earthquakes is effective when estimations are based on material intensity coefficients [24, 25, 26, 27, 28, 29, 30]. The material intensity coefficient varies according to the number and type of dwelling structure (detached dwelling, complex dwelling, etc.), type of building material (wooden, concrete, etc.), the household characteristics (number in household, property owner’s age, years of occupation, income, etc.), location of dwelling (urban or rural), and type of disaster waste (wood chips, concrete, stone, rubble, scrap metal, etc.) Identification is essential because treatment and recycling methods vary for each category.

Table 1 Material intensity coefficients

Methods	Types			Source
Created based on the actual amount of disaster waste in past earthquakes	Wooden dwelling (Combustibles) [ton/m^2]		0.19	[1]
	Wooden dwelling (Incombustibles) [ton/m^2]		0.5	
	Concrete dwelling (Combustibles) [ton/m^2]		0.12	
	Concrete dwelling (Incombustibles) [ton/m^2]		0.99	
	Wooden dwelling [ton/m^2]		0.62	[21]
	Concrete dwelling [ton/m^2]		0.85	
	Dwelling damaged by tsunami [ton/dwelling]		117	[5]
	Dwelling damaged by earthquake [ton/dwelling]		161	
Created based on stocks extant in area	Dwelling materials [kg/m^2]	Gravel	219.6	[6]
		Cement	88.1	
		Wood	2.8	
		Glass	29.8	
		Pottery	76.1	
		Iron	9.1	
		Aluminium	2.8	
		Others	3.00	
	Consumer durables [kg/dwelling]	Refrigerators	80.8	[6]
		Washing machines	50.0	
		Air-conditioners	133.1	
		TV sets	45.2	
		Cars	2,358	

Multiple studies attempt to estimate disaster waste generation instantly and accurately using remote sensing technology [31, 32, 33, 34, 35, 36]. Remote sensing technology is able to observe the earth's surface in high resolution using satellites and can create a spatial record of the degree of destruction to buildings in the affected area before and after an earthquake. These methods are based on the accumulation of artificial stock in the area.

Although the material intensity coefficient method can easily calculate disaster waste generation, the coefficient provides site-specific data because the data is identified by the affected area. However, future earthquakes may damage areas different than those mentioned above. Accumulated amounts of artificial capital stock differ at the city scale (population, population density, number of dwellings, aging rate, etc.). Therefore the method that relies on extant data risks a poor fit in terms of the material intensity coefficients if the potential disaster waste generation were estimated based on future earthquakes. In contrast, the second method appropriately estimates the potential amount of waste generated by accommodating the city scale and future earthquakes [37, 38, 39, 40]. Many studies assume the occurrence of earthquakes at a certain point in time in order to easily estimate the potential waste. There are a few studies that considered when an earthquake or tsunami might occur. In the cities, the population, number of structures, etc. change from year to year, as does the accumulated artificial capital stock. This means that the amount of potential waste will also vary at the time of an earthquake. Although it is impossible to predict exactly when earthquakes will occur, the uncertainty of the time of occurrence greatly affects discussion of effective disaster prevention measures. To avoid such uncertainty, some studies estimate potential disaster waste generation by assuming a variety of social situations such as future decreases in population [13, 41, 42].

It should be noted that there is a gap between estimates of potential waste and the actual amounts collected by local municipalities. Because they do not remove the foundations of structures and tsunami and floods drain waste into rivers and the open ocean. For example, some studies [43, 44] report that the actual amount of waste collected by local governments was only 50–60% of the estimates derived from surveys of past disasters.

2.2. Disaster waste management

Figure 1 shows the evaluation flow of disaster waste management. In the previous section, estimation methods were reviewed. These results are visualized as a spatial distribution using the GIS. Temporary storage sites and treatment facilities are also visualized as a spatial distribution. These visuals help to systematize the real disaster waste management process from transportation network to treatment. Next, a flow for disaster waste treatment is designed, and data for environmental and economic evaluations are surveyed. Comparing disaster waste management in Japan and the United States, nearly the same strategies for decision making are described in their treatment plans, including how to estimate disaster waste generation, setting up temporary storage sites, and the handling of disaster waste treatment [5, 9]. However, these plans lack evaluation from both environmental and economic perspectives. If economic considerations are evaluated, environmental concerns are slighted. As described later in Figure 1, this study emphasizes the necessity of evaluating both environmental and economic implications in disaster waste management.

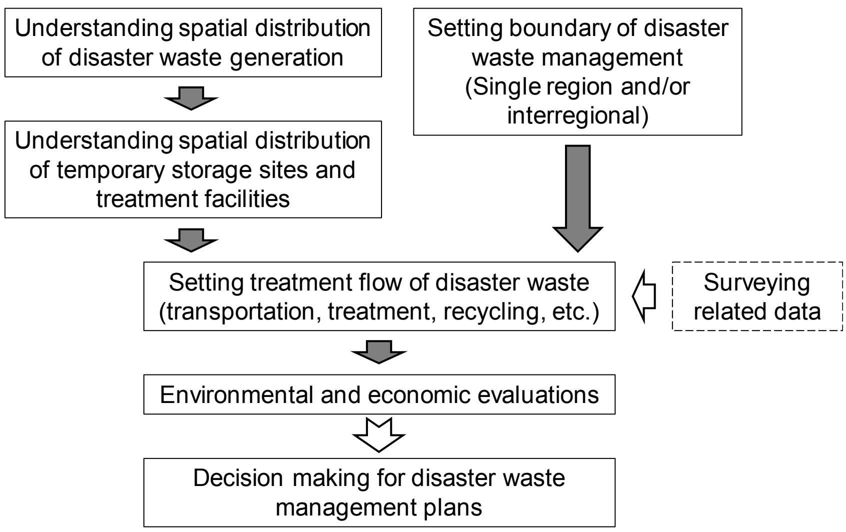


Figure 1 Evaluation flow of disaster waste management

At this point, the question arises as to whether management should be of a single region or an area comprising many regions (interregional) but with fixed boundaries. The greater the area contained within the boundary the greater the size of the transportation network needed, which also causes an additional environmental burden. When decision makers consider the management of an interregional area, cooperation among local municipalities and local residents is indispensable. Figure 2 shows an example of the flow of disaster waste management in the 2016 Kumamoto Earthquakes. Disaster waste generated in the affected areas is first transported to the primary temporary storage site. Then, waste is separated by type at the secondary temporary storage site. Bulky waste and/or complex waste are separated after crushing. Then separated waste is either incinerated, recycled, or deposited in a landfill, depending on the type of waste. The two major recycling methods are the recycling of material or the recovery of energy as fuel.

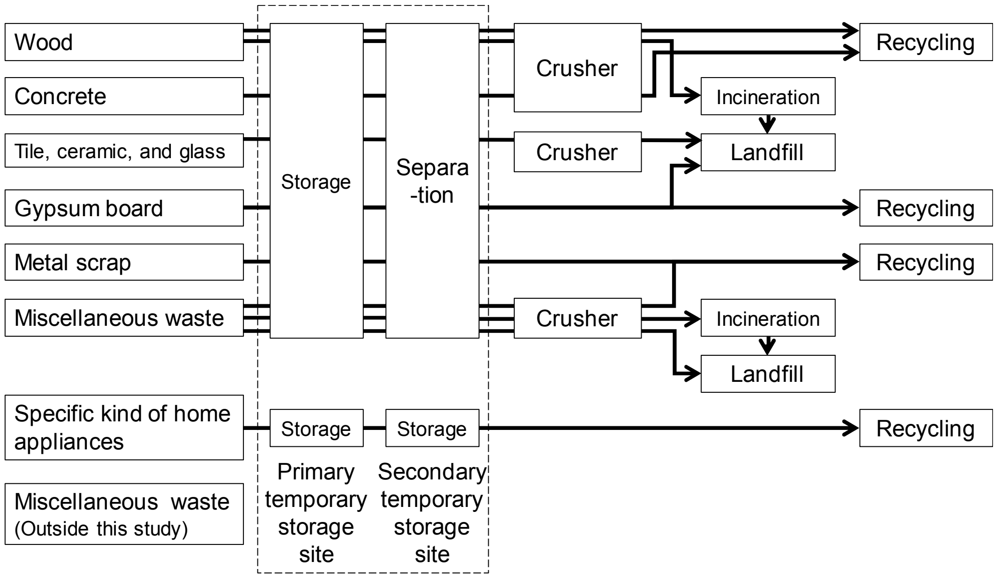


Figure 2 Treatment flow of disaster waste [10], 45]

Some studies have systematically evaluated disaster waste management. These studies focus on some of the processes involved in transportation and temporary storage sites using GIS [46, 47, 48, 49, 50, 51]. They target the entirety of disaster waste management, conducting environmental and/or economic evaluations of the 2011 Great East Japan Earthquake or the Nankai Trough Earthquake [52, 53, 54, 55], applying LCA and LCC approaches.

Life cycle thinking can conceive of the flow of disaster waste through an integrated system. Environmental and economic evaluations using LCA and LCC have a high utility because they clarify which processes cause a greater environmental burden [6, 7, 10, 56, 57]. In the LCA and LCC, environmental burdens and cost are calculated by multiplying the amount of collected, transported, and treated disaster waste and environmental and economic intensity. Table 2 shows an example of environmental and economic intensity data. These intensity data were calculated from actual values collected at disaster waste management sites and through statistical surveys as well as other methods. In addition, they clarify which environmental burdens deserve the most attention. For example, the authors [6, 7] have elsewhere shown that the cost of temporary incinerators cannot be ignored in the life cycle cost, and that reducing SO_x emissions should be given priority over CO_2 emissions. Studies that examine the system in its entirety often employ spatial distributions for road transportation networks, candidate locations for temporary storage sites, and locations of waste treatment facilities derived from GIS. Since they are a reflection of reality, these studies are able to propose highly feasible treatment plans. Treatment plans that take into account spatial information might also provide important information for volunteers working in affected areas. Volunteers are responsible for such activities as removing and transporting disaster waste. In recent years, numerous apps for smart phones, and other mobile devices, that support disaster recovery have been developed by private enterprises. By combining these apps and the treatments plans, volunteers might have immediate access to information (for example, where disaster waste should be removed to, which temporary storage spaces are empty or full, or whether there is traffic congestion). It is expected that apps that maximize efficiency be developed.

Table 2 Environmental and economic intensity data [10]

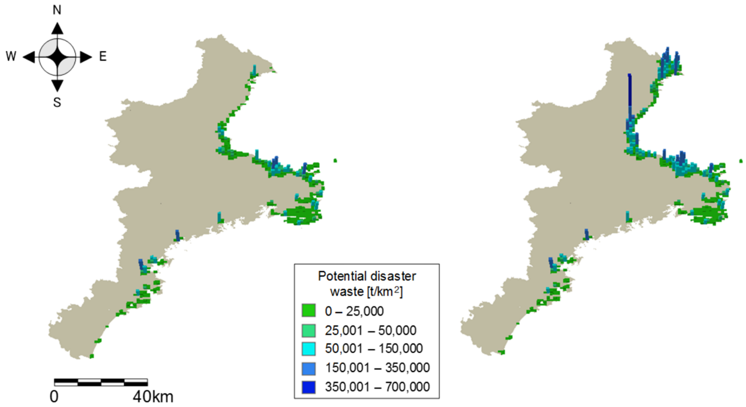
	Transportation [via 10 t truck]	Temporary storage site	Incineration		Crusher	Landfill
			For MSW	For industrial waste		
Unit	[/tkm]	[/ton]	[/ton]	[/ton]	[/ton]	[/ton]
CO_2 [kg/]	0.13	2.21×10^{-4}	906	807	51.1	79
SO_x [kg/]	6.32×10^{-6}	4.4×10^{-8}	5.41×10^{-1}	8.82×10^{-2}	4.84×10^{-3}	4.40×10^{-2}
NO_x [kg/]	1.09×10^{-5}	3.86×10^{-7}	6.26×10^{-1}	3.52×10^{-1}	2.04×10^{-2}	1.42×10^{-1}
PM [kg/]	6.68×10^{-5}	1.78×10^{-23}	6.23×10^{-3}	1.36×10^{-14}	3.16×10^{-16}	3.22×10^{-3}
Cost [USD/]	–	1,370	1,570	1,590	450	1,070
Ash [t/]	–	–	0.12	0.12	–	–

Proposed treatment plans must discuss the following factors: the numbers and locations of temporary storage sites, the redundant capacity of waste treatment facilities, number of trucks in transportation network, number of waste treatment facilities and temporary incinerators, expectations of damage to road networks, length of time required to restore road networks, and so on [53, 58, 59, 60, 61, 62, 63, 64, 65]. In addition, the cooperation of residents is indispensable for disposal and treatment, because residents living in affected areas (excepting children, the injured, and the elderly) can assist in transporting waste to temporary storage sites. The waste is often separated and treated in the affected area. With environmental burdens like air pollution and the noise of trucks used for transport, local separation and treatment negatively impacts residents [62, 63]. Even when treated at a site remote from the affected area, the environmental impact is unacceptable. For example, when waste is contaminated with radioactive materials, as occurred in the 2011 Great East Japan Earthquake, and a proposal is made to treat the waste in a location far from the affected area, many residents living near the proposed site were opposed to the plan [66]. Thoughtful management acts as a powerful risk assessment tool when decision makers elicit public involvement in a disaster prevention or response-related measure.

3. Disaster waste prevention

This section focuses on the effect of flood-prevention facilities on disaster waste prevention. The authors have developed methods for evaluating potential waste generation and waste management [7, 67]. This section discusses the results of these methods and their significance for disaster waste prevention. The Nankai Trough Earthquake, predicted to occur in the Mie prefecture of Japan, serves as the case study. If the Nankai Trough Earthquake were to occur as predicted, the Mie prefecture would experience an earthquake over 94.7% of the total area (5 777 km^2) with a JMA seismic intensity of 6 or greater and a tsunami affecting 4.9% of the total area (283 km^2) [68]. In many cases of earthquakes in subduction zones, tsunamis and flooding occur after the earthquake. The Great East Japan Earthquake was of this type. Seismic activity caused severe damage but tsunamis and flooding also caused extensive damage. The predicted Nankai Trough Earthquake will be the same type of earthquake, and so, it is quite important to prepare countermeasures for subduction zone earthquakes. The areas that can expect to be affected by tsunami and flooding are residential and industrial areas. The damage to human life and the economy would be catastrophic. The Mie Prefectural Government [69] envisaged two cases: (1) flood-preventing facilities such as flood barriers and breakwaters are not damaged by the earthquake and fulfil the role for which they are designed (Case 1: Flooding after the earthquake can be controlled) and (2) flood-preventing facilities are destroyed by the earthquake and cannot function as designed (Case 2: Flooding after the earthquake cannot be controlled). On this basis, the potential disaster waste generation and environmental burden of the two scenarios were quantified and compared. The difference between the two scenarios should correspond to the effect of disaster waste prevention.

Figure 3 shows the spatial distribution of potential waste: about 19.1 million tons in Case 1 and about 21.1 million tons in Case 2. The effect of disaster waste prevention corresponds to about 2.0 million tons. In order to maintain their function even after an earthquake, the old flood-prevention facilities should be renovated to a higher level of seismic reinforcement. According to the Mie prefectural government [70], the total length of the flood-prevention facilities to be renovated is about 569 km, and this length corresponds to almost the entire coastal line of the prefecture. Renovating the flood-prevention facilities is required not only to protect the lives and property of local residents, but for the sake of preventing waste. Although the renovation budget is hefty, a cost-benefit analysis comparing the results of failure of the flood-preventions facilities to renovation costs would be of great benefit for decision makers.

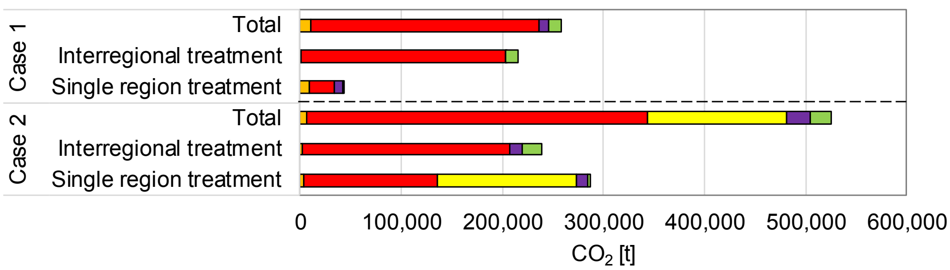


(a) Case 1 (b) Case 2

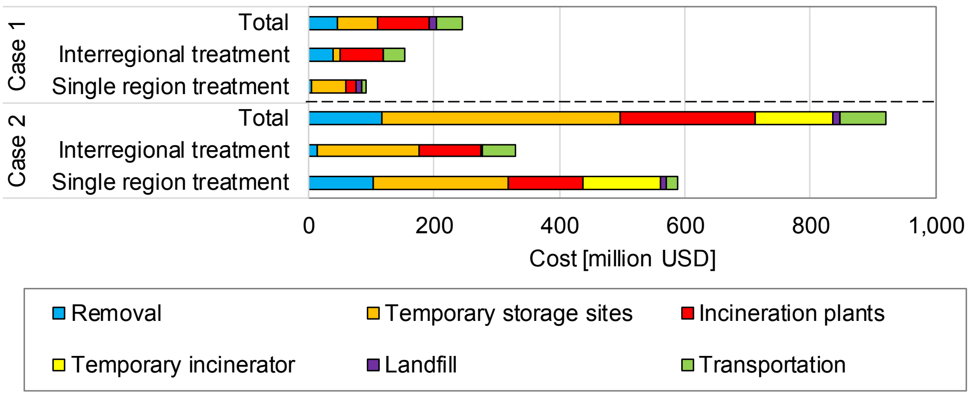
Figure 3 Spatial distribution of potential disaster waste [67]

Note: Case 1: Flooding after the earthquake can be controlled and Case 2: Flooding after the earthquake cannot be controlled.

Figure 4 shows costs of CO_2 emissions for disaster waste management. The treatment of combustibles from structures produced 2.6 million tons of CO_2 and cost 246 million USD in Case 1 and 5.3 million tons and 920 million USD in Case 2. These results emphasize the importance of disaster waste prevention.



(a) CO_2



(b) Cost

Figure 4 CO_2 and cost [7]

Note: Case 1: Flooding after the earthquake can be controlled and Case 2: Flooding after the earthquake cannot be controlled.

4. Summary and outlook

This paper reviewed research trends in disaster waste management of earthquakes in Japan. Three such trends were noted: estimations of potential disaster waste, systematic evaluations of disaster waste management, and necessity for disaster waste prevention. Disaster waste prevention is especially important from the viewpoint of environmental burden and cost.

The calculation of the effect of disaster prevention focused on hardware-side interventions such as renovation of flood-prevention facilities. In addition, interventions on the software side, such as changing the lifestyle of residents, should be discussed. The authors have investigated what kinds of lifestyle changes might assist disaster waste prevention, such as restricting the number of vacant buildings in an area and the reinforcement or reduction of consumer durables.[2] The authors call the integration of such interventions a “disaster reduction lifestyle.” One reason for the necessity of a disaster reduction lifestyle is the declining birth rate and aging population of Japan. This demographic trend has increased the number of vacant buildings, particularly in local cities [71]. Elderly people also tend to possess more consumer durables, such as chests of drawers, cupboards, and TVs, than younger generations [72]. Earthquake retrofitting of consumer durables is useful not only for the preservation of human life but also the prevention of waste accumulation after an earthquake. Preliminary reductions of surplus and unnecessary consumer durables is also effective, and some studies have investigated these conditions of surplus in the residence of the elderly [73, 74].

The Japanese Cabinet Secretariat [75] has proposed the following fundamental actions in their “guideline for national resilience”: all businesses and residents must protect themselves, help each other, and act proactively without the intervention of local municipal authorities. This will also expedite the removal of disaster waste because it will encourage locals to remove and transport waste on their own. In addition, uninjured adults can assist the elderly or injured with removal and transportation. Of course, although the cooperation of volunteers from outside the affected area is vital, the hard work of residents within the affected area is indispensable to the smooth advance of the initial stages of recovery after an earthquake. However, if an earthquake hits an area with a much larger population of elderly residents, a greater number of victims is likely, also increasing the difficulty of waste removal This will increase the work load for the local work force and volunteers. This issue is not unique to Japan, and similar things might occur in other countries that have current or

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[2] See reference [40].

future aging issues. To avoid such a tragedy, measures must be implemented to prevent waste from the perspectives of both hardware and software. Local municipalities have discussed plans that focus on transportation and treatment of waste. The implementation of disaster reduction lifestyles is an integral part of more comprehensive plans that reflect the reality of local municipalities.

Acknowledgments

This research was supported by the Environmental Research and Technology Development Fund (3K143015).

References

[1] Hyogo Prefectural government, The treatment of the disaster waste by Great Hanshin-Awaji Earthquake https://web.pref.hyogo.lg.jp/kk41/documents/000045493.pdf, 1997 (accessed 27 November 2018). [in Japanese]

[2] Japan Reconstruction Agency, The treatment of the disaster waste by Great East Japan Earthquake, 2014 http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-10/20140425_shinchoku140331.pdf (accessed 27 November 2018). [in Japanese]

[3] Cabinet Office government of Japan, Disaster Management Basic Plan, 2015 http://www.bousai.go.jp/taisaku/keikaku/kihon.html (accessed 27 November 2018). [in Japanese]

[4] Japan Ministry of Environment, Guideline for disaster waste recycling, 2017 http://kouikishori.env.go.jp/archive/h23_shinsai/implementation/recycling/ (accessed 27 November 2018). [in Japanese]

[5] Japan Ministry of Environment, Disaster Waste Countermeasure Guidelines, 2014 http://kouikishori.env.go.jp/action/investigative_commission/grand_design/pdf/h2603report.pdf (accessed 27 November 2018). [in Japanese]

[6] T. Tabata, Y. Wakabayashi, P. Tsai, T. Saeki, Environmental and economic evaluation of pre–disaster plans for disaster waste management, Waste Manag. 61 (2017) 386-396. https://doi.org/10.1016/j.wasman.2016.12.020.

[7] Y. Wakabayashi, P. Tsai, T. Tabata, T. Saeki, Life cycle assessment and life cycle costs for pre–disaster waste management systems, Waste Manag. 68 (2017) 688-700. https://doi.org/10.1016/j.wasman.2017.06.014.

[8] F. He, J. Zhuang, Balancing pre-disaster preparedness and post-disaster relief, Eur J Oper Res. 252 (2016) 246-256. https://doi.org/10.1016/j.ejor.2015.12.048.

[9] US EPA, Planning for natural disaster debris. https://www.epa.gov/large-scale-residential-demolition/disaster-debris-planning, 2008 (accessed 27 November 2018).

[10] T. Tabata, Y. Wakabayashi, P. Tsai, T. Saeki, Environmental and Economic Evaluation of Disaster Waste Management, Chem Eng Trans. 61 (2017) 31-36. https://doi.org/10.3303/cet1761003.

[11] N. Yamazaki, A countermeasure construction for earthquake and liquefaction resistance, Jpn Geotech Soc. 63 (2015) 30-31. [in Japanese]

[12] A. Takahashi, M. Okamura, Seismic performance assessment of river levees, Jpn Geotech Soc. 63 (2015) 6-9. [in Japanese]

[13] M. Maeda, A. Onishi, Understanding of the amount of disaster waste and reduction effect of earthquake resistant and evacuation in western part of Shizuoka Prefecture, J Jpn Soc Civil Eng, Ser G. 73 (2017) 143-158. https://doi.org/10.2208/jscejer.73.143. [in Japanese]

[14] A. Hirayama, Y. Kawata, Reduction effect of potential disaster waste by retrofiting earthquake resistant dwelling, Proc 24th Jpn Soc Mater Cycles Waste Manag. (2013) 167-168. https://doi.org/10.14912/jsmcwm.24.0_167. [in Japanese]

[15] Y. Mori, I Hamaguchi, T. Oomori, K. Nakano, T. Matsumura, Y. Yamamoto, Y. Yoshida, Consciousness for disaster prevention and behavior, Proc 68th Annu Conf Jpn Soc Home Econ, (2016) 86. https://doi.org/10.11428/kasei.68.0_285. [in Japanese]

[16] T. Miura, K. Kobayashi, T. Yamashita, S. Tanaka, D. Isobe, Motion analysis of Quake-proof furniture placed in RC building under seismic excitation, Trans Jpn Soc Comput Eng Sci, 2 (2018) 20182005. https://doi.org/10.11421/jsces.2018.20182005. [in Japanese]

[17] H. Morita, A. Onishi, A study on preference of residents on house relocation for mitigating disaster waste caused by tsunami, Soc Env Sci Jpn, 30 (2017) 357-364. https://doi.org/10.11353/sesj.30.357. [in Japanese]

[18] A. Hirayama, S. Iwai, S. Hamada, S. Iwashita, K. Manabe, investigating a method for disaster waste generation using mesh method in first arrival of earthquake, Proc 27th Jpn Soc Mater Cycles Waste Manag. (2016) 151-152. https://doi.org/10.14912/jsmcwm.27.0_151. [in Japanese]

[19] S. Mizutani, N. Abe, Y. Kanjo, Estimating potential disaster waste generation derived from building stock in Osaka, Japan, Proc 23th Jpn Soc Mater Cycles Waste Manag. (2012) 189-190. https://doi.org/10.14912/jsmcwm.23.0_189. [in Japanese]

[20] J. Xiao, H. Xie, C. Zhang, Investigation on building waste and reclaim in Wenchuan earthquake disaster area, Resour Conserv Recy. 61 (2012) 109-117. https://doi.org/10.1016/j.resconrec.2012.01.012.

[21] H. Takatsuki, S. Sakai, S. Mizutani, Disasters and State of Waste, Generation Basic Units of Disaster Waste and Change of Constitution of Normal Waste, Mater Cycles Waste Manag Res. 6 (1995) 351-359. https://doi.org/10.3985/wmr.6.351. [in Japanese]

[22] T. Suzuki, T. Shimotomai, D. Nemizu, T. Wakabayashi, Disaster waste generation at coastal area of Sanriku area affected by the 2011 Great East Japan Earthquake, Proc 24th Jpn Soc Mater Cycles Waste Manag. (2013) 169-170. https://doi.org/10.14912/jsmcwm.24.0_169. [in Japanese]

[23] M. Yamanaka, Estimating tsunami disaster waste generation, Proc 2012 Annu Jpn Soc Eng Geol, (2012) 49-50. [in Japanese]

[24] T. Katsumi, H. Hayashi, M. Kamon, Generation and management of disaster waste due to the Great Hanshin-Awaji Earthquake, Disaster Prev Res Inst Annu, 39B-2 (1996) 37-50. [in Japanese]

[25] T. Ozaki, T. Morioka, Sensitivity analysis of mass per unit of the disaster waste, Proc 28th Jpn Soc Mater Cycles Waste Manag. (2017) 159-160. https://doi.org/10.14912/jsmcwm.28.0_159. [in Japanese]

[26] T. Inui, H. Komine, H. Ohno, M. Kazama, M. Okawara, M. Monma, Generation and immediate treatment of disaster debris by the 2011 off the pacific coast of Tohoku earthquake and tsunami, Jpn Geotech Soc. 61 (2013) 4-7. [in Japanese]

[27] Y. Tsurubo, Y. Moriguchi, J. Nakatani, Comparative analysis of generation and management of disaster waste from the Great East Japan Earthquake, J Jpn Soc Civil Eng, Ser G. 70 (2014) II_23-II_32. https://doi.org/10.2208/jscejer.70.II_23. [in Japanese]

[28] T. Takuya, S. Sato, A. Ohuchi, Consideration about the amount presumption system of disaster wastes leaned from the Great East Japan Earthquake, Proc 74th Nat Con Info Proc Soc Jpn, (2012) 287-288. [in Japanese]

[29] Y. Kobayashi, H. Konishi, M. Hirohata, K, Baba, Disaster waste treatment after the 2016 Kumamoto Earthquake, Proc 28th Jpn Soc Mater Cycles Waste Manag. (2017) 161-162. https://doi.org/10.14912/jsmcwm.28.0_161. [in Japanese]

[30] S. Hashimoto, Y. Terashima, On the waste generation rates of building demolition, J Jpn Soc Waste Manag Expert, 10 (1999) 35-44. https://doi.org/10.3985/jswme.10.35. [in Japanese]

[31] K. Hisa, Y. Kageyama, M. Nishida, H. Ouchi, T. Takatani, Y. Nakamura, Basic investigation for resolution enhancement to estimate amount of disaster waste, Proc 75th Nat Con Info Proc Soc Jpn, (2013) 547-548. [in Japanese]

[32] R. Tonegawa, H. Iizuka, M. Yamamoto, M. Furukawa, H. Oouchi, Automatic judgement of collapsed dwelling using liner detection of airborne imaginary to estimate disaster waste generation, Proc 25th Jpn Soc Mater Cycles Waste Manag. (2014) 109-110. https://doi.org/10.14912/jsmcwm.25.0_109. [in Japanese]

[33] H. Tanikawa, S. Managi, C.M. Lwin, Estimates of Lost Material Stock of Buildings and Roads Due to the Great East Japan Earthquake and Tsunami, J Ind Ecol. 18 (2014) 421-431. https://doi.org/10.1111/jiec.12126.

[34] H.Y. Kung, H.H. Ku, C.I. Wu, C.Y. Lin, Intelligent and situation-aware pervasive system to support debris-flow disaster prediction and alerting in Taiwan, J Netw Comput Appl. 31(2008) 1-18. https://doi.org/10.1016/j.jnca.2006.06.008.

[35] H.Y. Kung, C.H. Chen, H.H. Ku, Designing intelligent disaster prediction models and systems for debris-flow disasters in Taiwan. Expert Syst Appl. 39 (2012) 5838-5856. https://doi.org/10.1016/j.eswa.2011.11.083.

[36] A. Stolle, M. Langer, J.H. Blöthe, O. Korup, On predicting debris flows in arid mountain belts. Glob Planet Change, 126 (2015) 1-13. https://doi.org/10.1016/j.gloplacha.2014.12.005.

[37] T. Ozaki, T. Morioka, Estimating earthquake and tsunami disaster waste generation by building properties, Proc 27th Jpn Soc Mater Cycles Waste Manag. (2016) 153-154. https://doi.org/10.14912/jsmcwm.27.0_153. [in Japanese]

[38] M. Yamanaka, N. Toyota, A Nonomura, S Hasegawa, Estimation of amount of tsunami disaster wastes for Shikoku districts by Tounankai-Nankai earthquake, J Soc Sci Mater Jpn, 63 (2014) 131-136. https://doi.org/10.2472/jsms.63.131. [in Japanese]

[39] T. Tabata, O. Zhang, Y. Yamanaka, P. Tsai, Creation and application of mass per unit database for potential waste generation derived from consumer durables using statistical and web information, J Jpn Soc Civil Eng, Ser G. 71 (2015) II_441-II_449. https://doi.org/10.2208/jscejer.71.II_441. [in Japanese]

[40] T. Tabata, H. Morita, A. Onishi, What is the quantity of consumer goods stocked in a Japanese household? Estimating potential disaster waste generation during floods, Resour Conserv Recy. 133 (2018) 86-98. https://doi.org/10.1016/j.resconrec.2018.02.012.

[41] K. Imai, H. Sao, M. Maeda, A. Onishi, An estimation of the amount of disaster waste produced by the Great earthquake along the Nankai trough in Kochi Prefecture, Proc 43th Annu Cmte Env Sys Jpn Soc Civil Eng, 43 (2015) 171-178. [in Japanese]

[42] A. Onishi, H. Sao, M. Maeda, Estimating earthquake and tsunami potential disaster waste generation derived from dwelling, Env Info Sci, 45-1 (2016) 76. [in Japanese]

[43] K. Imai, T. Saeki, Study on Effect of the Amount of Disaster Waste in Tsunami, Proc 11th meeting Inst Life Cycle Assess, Jpn, (2016). 376-377. [in Japanese]

[44] M. Tsurumaki, Y. Yamamoto, N. Yoshida, A basic study on prediction method of disaster waste based on regional material stock, J Jpn Soc Civil Eng, Ser G. 71 (2015) II_241-II_251. https://doi.org/10.2208/jscejer.71.II_241. [in Japanese]

[45] Kumamoto Prefectural government, Disaster waste management plan for 2016 Kumamoto Earthquakes, http://www.pref.kumamoto.jp/kiji_16209.html, 2016 (accessed 27 November 2018). [in Japanese]

[46] Y. Arai, Y. Ikeda, T. Inakazu, A. Koizumi, S. Mogi, S. Yoshida, S. Iino, Model analysis of transportation planning for earthquake disaster debris, J Jpn Soc Civil Eng, Ser G. 71 (2015) II_263-II_270. https://doi.org/10.2208/jscejer.71.II_263. [in Japanese]

[47] P. Pramudita, E. Taniguchi, A. G. Qureshi, Location and routing problems of debris collection operation after disasters with realistic case study, Procedia Soc Behav Sci. 125 (2014) 445-458. https://doi.org/10.1016/j.sbspro.2014.01.1487.

[48] Y. Yanada, C. Kayo, K. Tachio, M. Yamada, S. Hashimoto, The disaster waste management plan for a Nankai trough earthquakes, Proc 10th meeting Inst Life Cycle Assess, Jpn, (2015) 24-25. [in Japanese]

[49] C. Cheng, G.R. Thompson, Application of boolean logic and GIS for determining suitable locations for Temporary Disaster waste management Sites. Int J Disaster Risk Reduct, 20 (2016) 78-92. https://doi.org/10.1016/j.ijdrr.2016.10.011.

[50] K. Onan K., F. Ülengin, B. Sennaroğlu, An evolutionary multi-objective optimization approach to disaster waste management. Expert Syst Appl, 42 (2015) 8850-8857. https://doi.org/10.1016/j.eswa.2015.07.039

[51] J. Kim, A. Deshmukh, M. Hastak (2018) A framework for assessing the resilience of a disaster debris management system. Int J Disaster Risk Reduct, 28 (2018) 674-687. https://doi.org/10.1016/j.ijdrr.2018.01.028.

[52] T. Sasao, Cost and efficiency of disaster waste disposal: A case study of the Great East Japan Earthquake. Waste Manag, 58 (2016) 3-13. https://doi.org/10.1016/j.wasman.2016.09.032.

[53] J. Ikawa, T. Nakakubo, A. Tokai, Analysis on measure effectiveness of combustible disaster waste management based on resilience, J Jpn Soc Civil Eng, Ser G. 71 (2015) II_253-II_262. https://doi.org/10.2208/jscejer.71.II_253. [in Japanese]

[54] T. Kazunori, Cost-benefit analysis of disaster waste management under regional general waste management in normal period, Proc 11th meeting Inst Life Cycle Assess, Jpn, (2016) 174-175. [in Japanese]

[55] J. Crowley, A measurement of the effectiveness and efficiency of pre-disaster debris management plans, Waste Manag. 62 (2017) 262-273. https://doi.org/10.1016/j.wasman.2017.02.004.

[56] P.P. Joana, L. Lisa, Economic and environmental benefits of waste-to-energy technologies for debris recovery in disaster-hit Northeast Japan, J Clean Prod. 112 (2016) 4419-4429. https://doi.org/10.1016/j.jclepro.2015.05.083.

[57] Á. Lorca, M. Çelik, Ö. Ergun, P. Keskinocak, A decision-support tool for post-disaster debris operations, Procedia Eng. 107 (2015) 154-167. https://doi.org/10.1016/j.proeng.2015.06.069.

[58] C. Kayo, T. Ishigaki, M. Yamada, M. Osako, K. Tachio, Discussion on wide-area treatment of disaster waste by 2011 Great east Japan earthquake, 2015, http://www.jesc.or.jp/Portals/0/center/library/H27saigai1.pdf. [in Japanese]

[59] S. Inazumi, H. Ohtsu, N. Okuno, Necessity of broad-based disposal for disaster waste based on environmental impacts, Mater Cycles Waste Manag Res, 23 (2012) 199-206. https://doi.org/10.3985/jjsmcwm.2120411. [in Japanese]

[60] N. Takeda, Damage situation of municipal solid waste treatment facilities by 1995 Great Hanshin-Awaji Earthquake, J Jpn Waste Manag Assoc, 48 (1995) 28-33. [in Japanese]

[61] Japan Waste Management Association, Damage situation of municipal solid waste treatment facilities by the 2011 Great East Japan Earthquake, http://www.jwma-tokyo.or.jp/asp/saigai/20110420sisetuhigai_syukei.pdf, 2011 (accessed 27 November 2018). [in Japanese]

[62] N. Hirayama, Y. Kawata, Wide-area cooperative measures in the emergency debris operation on the huge earthquake disasters, J Jpn Soc Civil Eng, Ser G. 63 (2007) 112-119. https://doi.org/10.2208/jscejg.63.112. [in Japanese]

[63] N. Hirayama, Y. Kawata, Wide-area cooperative measures in the emergency debris operation in the case of the Tokai earthquake, Disaster Reduction Manag, 2 (2007) 134-140. [in Japanese]

[64] S. Sou, Examining combustibles disaster waste disposal, J Jpn Waste Manag Assoc, 26 (2015) 228-236. [in Japanese]

[65] P. Tsai, T. Takashi, A. Onishi, T. Tabata, Reduction capacity of Japan's waste incineration plants, J Jpn Waste Manag Assoc. 29 (2018) 92-103. https://doi.org/10.3985/jjsmcwm.29.92. [in Japanese]

[66] P. Tsai, T. Tabata, H. Shirakawa, Analysis of residents' awareness against wide-area treatment of potential disaster waste, J Jpn Waste Manag Assoc, 70 (2017) 275-284. [in Japanese]

[67] A. Onishi, T. Tabata, Understanding of mitigation effect of tsunami disaster wastes from buildings generated to difference in function of seawall, Rep City Plan Inst Jpn, 16 (2017) 78-81. [in Japanese]

[68] Mie Prefectural government, Disaster waste management plan, http://www.pref.mie.lg.jp/common/01/ci500005217.htm, 2015 (accessed 27 November 2018). [in Japanese]

[69] Mie Prefectural government, M-GIS, http://www.pref.mie.lg.jp/m-gis, 2017 (accessed 27 November 2018). [in Japanese]

[70] Mie Prefectural government, Situation of coastal management for disaster prevention, https://www.mlit.go.jp/river/shinngikai_blog/kaigankanrinoarikata/dai02kai/dai02kai_siryou2.pdf, 2013 (accessed 27 November 2018). [in Japanese]

[71] Japan Ministry of Internal Affairs and Communications, 2013 Dwelling and land survey of Japan, http://www.stat.go.jp/data/jyutaku/, 2015 (accessed 27 November 2018). [in Japanese]

[72] Japan Ministry of Internal Affairs and Communications, 2009 National Survey of Family Income and Expenditure of Japan, http://www.stat.go.jp/data/zensho/2009/, 2010 (accessed 27 November 2018). [in Japanese]

[73] S. Suzuki, M. Takada, D. Numata, R. Tajima, A. Ritsuto, Y. Matsufuji, Current situation regarding hoarded bulk wastes cleared from elderly households, Mater Cycles Waste Manag Res, 28 (2017) 200-209. [in Japanese]

[74] D. Numata, S. Suzuki, M. Takada, R. Tajima, Investigating for disposal of unnecessary dwelling stock before natural disasters, Proc 39th Annu Conf Jpn Waste Manag, (2018) 341-343. [in Japanese]

[75] Japan Cabinet Secretariat, Guideline for national resilience, https://www.cas.go.jp/jp/seisaku/kokudo_kyoujinka/, 2017 (accessed 27 November 2018). [in Japanese]