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(Citation)
Resources Conservation and Recycling,133:86-98

(Issue Date)
2018-06

(Resource Type)
journal article

(Version)
Accepted Manuscript

Title

What is the quantity of consumer goods stocked in a Japanese household? Estimating potential disaster waste generation during floods

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Abstract

This study aims to estimate micro material stock derived from consumer goods m fundamental data such as possession and expenditure of consumer goods in housing, considering the type of housing and class of total floor area of housing. A questionnaire survey of residents living in the eight cities of the Tama river basin was conducted to clarify the possession and expenditure of consumer goods in units of items/housing and JPY/housing. Identified consumer goods were 14 types and 97 items. The questionnaire also asked the storeys on which the consumer goods are installed. Material intensity coefficients (MIC) regarding the weight of consumer goods were calculated based on web–based and statistical surveys in units of kg/item and kg/USD. Micro material stock derived from consumer goods in housing totalled 5.84 tonnes (t) in detached housing and 5.71 t in complex housing. Amount of the micro material stock derived from consumer goods corresponds to 10.9 % of the macro material stock derived from detached housing. Reliability and validity of questionnaire results and the MIC were confirmed through two types of sensitivity analysis. As a case study, the total weight of all consumer goods in Kawasaki City was calculated as 3,667,000 t. The disaster waste derived from consumer goods considering the flood damage was estimated based on the total weight of all consumer goods in the city. The resulting estimation was 229,000 t. This estimation is 0.72 times bigger than the above-mentioned result that considered the storeys on which the consumer goods are installed.

Keywords

Micro material stock, consumer goods, material intensity coefficients for number and weight of consumer goods, disaster waste, questionnaire survey

1. Introduction

We live our lives surrounded by anthropogenic stock. This anthropogenic stock, also called material stock such as ore, oil and biomass. Anthropogenic stock is classified into two types: macro material stock and micro material stock. The former includes infrastructure and buildings. The latter includes appliances, furniture, clothes, bags, and other small items. The micro material stock is usually stocked in housing as consumer goods. The anthropogenic stock is converted to waste when its lifetime is over. Avoiding the conversion of anthropogenic stock to waste is desirable, according to 3R (Reduce, Reuse and Recycling) thinking and the circular economy (Japan Ministry of Environment (JMOE) 2008; European Commission 2017).

The incident in which anthropogenic stock is converted to waste in a moment is a natural disaster. Natural disasters, such as earthquakes, tsunamis, and floods, cause severe damage to human life and the anthropogenic stock people possess. In addition, a huge amount of disaster waste is generated after such disasters. Disaster waste is derived from anthropogenic stock. After natural disasters, disaster waste is collected and treated for the reconstruction of an affected area. The environmental burden and cost of treating disaster waste are not negligible (Tabata et al. 2017; Wakabayashi et al. 2017). He and Zhuang (2016) indicate that loss from natural disasters is determined not only by measures that are taken after the disasters but also by the disaster prevention measures that are taken before disasters. This thinking is also effective for disaster waste management measures. Maryono et al. (2015) identified one of the importance factors in the prevention is understanding of the amount and characteristic of disaster waste. Tajima et al. (2014) also indicate that the disaster waste management planning should be based on research findings and accurate knowledge on disaster agent and response. Fetter and Rakes (2012) and Hu and Sheu (2013) revealed that incentives for the disaster waste recycling reduces total cost of the disaster waste management. When local governments conduct simulations for disaster waste management measures in advance of such disasters to clarify the environmental burden and cost of disaster waste collection and treatment, understanding the amount and type of potential disaster waste is important in generating basic data for the simulation.

According to the basic disaster prevention plan published by the Japanese government, most of the disaster waste should be reused and/or recycled (Japan Central Disaster Management Council 2014). This policy is based on 3R thinking and is similar to circular economy thinking. Disaster waste is originally manufactured from natural resources. Although quick treatment of disaster waste is of primary importance for the reconstruction of the affected area, prioritising incineration, and landfill too quickly to reconstruct the affected area might lead to a waste of resources. This is true because plenty of natural resources are consumed in the reconstruction of anthropogenic stock in the affected area. The desirable policy is to utilise disaster waste as secondary materials for reconstruction. According to this policy, 81% of disaster waste and 99 % of tsunami debris were recycled for disaster waste treatment generated by the 2011 Great East Japan Earthquakes (JMOE 2017a).

Understanding the amount and type of disaster waste is effective in investigating disaster waste recycling measures. A popular method of estimating the type and amount of disaster waste is calculating the material intensity coefficients (MIC) of disaster waste generation per housing unit and calculating disaster waste by multiplying the MIC and damage functions. The damage function is determined by the type of natural disaster and degree of damage. Actual data identified by previous natural disasters are usually utilised (Takatsuki et al. 1995; Hirayama & Kawata 2005, Hirayama et al. 2009; Kung et al. 2012; Xiao et al. 2012; Nakayama et al. 2013; JMOE 2014; Stolle et al. 2015). However, this method has the following problems: (1) there is a validation date for the MIC because the MIC that were calculated on based on previous natural disasters might not be suitable for estimation against the latest natural disasters. The MIC vary over time because of technical changes in housing structure, such as building materials and (2) the total floor area of housing built in a rural area is usually larger than that of housing built in an urban area. Accordingly, the MIC that are calculated based on cases in an urban area is not suitable for use in a rural area. However, if there were no basic data for rural areas, utilising basic data for an urban area would be the only way. In that case, the problem resulting from the quality of estimation results not being assured would not be negligible.

To solve the above-mentioned problems, Tanikawa et al. (2014) developed a method for estimating disaster waste derived from housing using the geographic information system (GIS). The location, type, and amount of housing can be identified using the GIS. This method is advantageous because it does not require MIC calculated on the basis of previous natural disasters, and disaster waste can be estimated from the map data. This method can be applied to any scale of area if there is only map data. Tabata et al. (2016) also developed a method for estimating disaster waste derived from consumer goods, considering 18 types of home appliances and cars. They calculated the MIC for various consumer goods through a web-based survey. The amount and type of consumer goods possessed in housing can be identified using national statistical data and/or a questionnaire survey for consumers. This method can also estimate disaster waste, regardless of the scale of the area. Methods that were developed by Tanikawa et al. (2014) and Tabata et al. (2016) applied the thinking of material flow analysis. They estimated disaster waste using data regarding the macro and micro material stock in the area. These methods created a new approach in the field of disaster waste management.

The above-mentioned methods were originally used to estimate anthropogenic stock. There are two accountings to estimate anthropogenic stock: one is a bottom-up accounting, and the other is a top-down accounting. Gontia et al. (2018) indicates that the bottom-up accounting is also known as a coefficient-based method. According to Gontia et al. (2018), the bottom-up accounting estimates the physical size of the built-environment components in units of m^2 and m^3 and the MIC, also called as basic unit, which is specific to each component, in units of kg/m^2 and kg/m^3 using actual value and national statistical data. There are many studies using the actual data for estimating building material stock. For example, Liang et al. (2017), Miatto et al. (2017) and Schebek et al. (2017) estimated the building material stock utilising spatial data and its lifespan. Gontia et al. (2018) estimated the MIC for the residential buildings in Sweden by using actual architectural data. As the national statistical data, the Japanese government also conducts its‘ National survey of family income and expenditure and family income’, ‘Expenditure survey’, ‘Retail price survey’, and ‘Consumer behaviour survey’. These national statistical data inform us that we should use data such as the amount and types of consumer goods possessed in housing and the annual and monthly expenditures for consumer goods, groceries, education and insurance. The ‘UN Comtrade’ and ‘Trade statistics’ also provide transaction amounts and/or weights of each material and commodity. Chen and Graedel (2015), Lau et al. (2013), Nassar (2017), Oguchi et al. (2008), Tabata et al. (2016), and Tansel (2017) utilise this approach. Schiller et al. (2017) not only estimate consumer goods, but also residential and non-residential buildings. However, these statistical data do not address all the consumer goods stocked in housing. Statistics investigating expenditure trends for only a few months in a year have problems with data integrity. If statistical data regarding trade were utilised, surplus operations, such as the elimination of customs duty from each resource and commodity, were conducted. There are many consumer goods, and it is almost impossible to understand only the statistical data. Understanding these data requires much time and complicated work. For example, imagine counting the clothes at your home. There are various kinds of clothing, and laborious work is required to measure the weight of each. Although Tabata et al. (2016) estimated 18 types of consumer goods, they did not consider the micro material stock because other types of the consumer goods were outside of the study.

Top-down accounting estimates by using an input-output table. The input-output table is a table for understanding industrial activities through monetary flows; anthropogenic stock is estimated by converting monetary data into weight data. Schaffartzik et al. (2013), Eisenmenger et al. (2016), and López et al. (2017) utilise this approach. However, the input-output table is based on industrial activities, and only rough estimation of micro material stock is possible. With this approach, it is also difficult to treat all the consumer goods stocked in housing.

This study aims to estimate all the micro material stock utilising bottom-up and top-down accountings. This study also calculates MIC that can be utilised, irrespective of the scale of the area.

2. Materials and methods

Micro material stock derived from the consumer durables in an area is calculated by the following formulae that are based on Tabata et al. (2016).

$$s_{d,x}^{i} = \sum_{d=1}^{n} \left(P_{d,x}^{i} \times w_{d} \right) \tag{1}$$

$$S = \sum_{i=1}^{n} \sum_{x=1}^{n} \left(s_{d,x}^{i} \times F_{x}^{i} \right) \tag{2}$$

where *s* denotes the micro material stock derived from the consumer durables in a housing [kg]; *P* denotes the degree of possession in housing [items/household or USD/household]; *w* denotes the MIC of consumer durables [in either kg/item or kg/USD]; *d* denotes the type of consumer goods; *I* idenotes the type of housing (detached housing or complex housing); *x* denotes the total floor area of housing; *S* denotes the micro material stock derived from the consumer durables in the area [in kg]; and *F* is the number of the housing. Two types of the unit of *P* are used to query the amount and expenditure of consumer goods that inhabitants possess, using a questionnaire survey.

Key elements in estimating the micro material stock derived from consumer goods include the amount and type of consumer goods, considering the type of housing, total floor area, and the MIC of consumer goods (Inaba et al. 2017; Jones et al. 2015; Tabata et al. 2016). A reason why detached housing and complex housing are a major focus in

Japan is that ratio of residential buildings is 55 % in the detached housing and 42 % in the complex housing (Japan Ministry of Land, Infrastructure and Transport (JMLIT) 2015). Average total floor area in Japan is 129.84 m^2 in the detached housing and 48.95 m^2 in the complex housing (JMLIT 2015). Thus, considering the type of housing is important to estimate the micro material stock derived from consumer goods. In this study, the amount and type of consumer goods in units of items/housing and JPY/housing, considering the type of housing and total floor area, is clarified using the bottom-up approach with a questionnaire survey. The MIC of consumer goods is also calculated in units of kg/item and kg/JPY by combining the bottom-up approach, such as a web–based survey, and the top-down approach, such as the input-output table based on Fujie et al. (2001) and Tabata et al. (2016).

The questionnaire survey was conducted among inhabitants of the Tama river basin in Japan. Figure A.1 shows the location of the Tama river basin. The Tama river forms the boundary line between the Tokyo and Kanagawa prefectures. The basin area of the Tama river is 1,240 km^2, and the total length of the river is 138km. The population of the basin is approximately 3.8 million. The Tama river has often caused severe flood damage via breaches of the river wall due to heavy rain and typhoon. The Tama river basin is overpopulated because the basin is very close to the Tokyo metropolitan area. Most inhabitants live here in order to commute to work or go to school. The companies and factories are concentrated in the downstream part. If the river wall were destroyed by natural disasters, severe damage to the inhabitants and economy might occur. Therefore, the Japanese government made a hazard map of the Tama River basin and investigated disaster prevention measures (JMLIT 2016). Based on such situations, this study conducted a questionnaire survey in the eight cities shown in Figure A.1, where severe damage is expected.

After calculating the micro material stock, this study conducts a case study in Kawasaki City, one of the downstream cities of the Tama river basin. Kawasaki City has the greatest population (approximately 1.5 million) in the basin. This city concentrates many companies and factories.

2.1. Questionnaire survey

The questions related to the number of consumer goods that respondents possess in each household of eight towns shown in Figure A.1. Respondents answered the questionnaire via the internet. Table 1 shows the outline of the questionnaire survey. 97 items of consumer goods were identified in the survey. These items were classified into: (1) Household equipment, (2) Home appliances, (3) Air-conditioning equipment, (4) Audio-visual equipment, (5) Instrument, (6) Furniture, (7) Transportation equipment, (8) Interior accessories, (9) Kitchen/ household goods, (10) Clothes, (11) Bags/shoes/umbrella, (12) Education/entertainment goods, (13) Hairdressing/beauty equipment, and (14) Miscellaneous goods based on Japan's Ministry of Internal Affairs and Communications

(JMIAC) (2011). Type and name of items are shown in Table A.1. The survey period was from 27th to 28th December, 2016. The 416 respondents were citizens registered with a survey firm. The analysis was based on 415 valid responses. In this survey, two broad types of questions regarding possession of consumer goods were asked: questions for goods of types (1) through (5) and (7) asked for the amount of possession and questions for goods of types (6) and (8) through (14) asked for the expenditure incurred on these possessions. One reason for seeking expenditure was that residents many units of items, such as interior accessories and clothes, and consider it is a waste of time to count them. This troublesome work might lead to a decline in the number of responses and an increase in inappropriate answers.

Table 1 Outline of the questionnaire survey

(i) Questions about respondents Sex, age group, number of households including respondents, annual income of household, jobs, family form, married or unmarried, and presence and absence of children
(ii) Questions about housing Type of housing (detached housing, complex housing, and miscellaneous), construction type (wooden and not wooden), possession of housing (own, rental, and other), construction period (before 1962, 1963 to 1971, 1972 to 1980, 1981 to 1989, 1990 to 2001, after 2002, and unknown), total floor area (below 29 m^2, 30 m^2 to 49 m^2, 50 m^2 to 59 m^2, 60 m^2 to 69 m^2, 70 m^2 to 79 m^2, 80 m^2 to 99 m^2, 100 m^2 or above, and unknown), and storeys of detached housing/complex housing (one storey and two storeys or above)
(iii) Possession of consumer goods (Types (1) to (5) and (7) are targeted)
(iv) Expenditure to possess consumer goods(Types (6) and (8) to (14) are targeted) JPY 0, JPY 1 to JPY 4,999, JPY 5,000 to JPY 9,999, JPY 10,000 to JPY 29,999, JPY 30,000 to JPY 49,999, JPY 50,000 to JPY 99,999, JPY 100,000 to JPY 149,999, JPY 150,000 to JPY 199,999, JPY 200,000 to JPY 299,999, JPY 300,000 to JPY 399,999, JPY 400,000 to JPY 499,999, JPY 500,000 to JPY 749,999, JPY 750,000 to JPY 999,999, JPY 1,000,000 to JPY 1,499,999, JPY 1,500,000 to JPY 1,999,999, JPY 2,000,000 to JPY 2,999,999, JPY 3,000,000 to JPY 4,999,999 to JPY 9,999,999, JPY 10,000,000 to JPY 14,999,999, JPY 15,000,000 to PY19,999,999J, and JPY 20,000,000 and over
(v) Percentage of consumer goods installed on the first floor (detached housing only except for question [7])
(vi) Percentage of car parking location one storey and two storeys or above

*Note: 1JPY=0.0088USD (11/8/2017)

The survey also asked whether consumer goods are installed by respondents who live in detached housing with two or more storeys. This question is based on the fact that the damage for consumer goods varies, depending on whether the consumer goods are installed on the first floor or on higher floors. This is particularly true for damage caused by a flood or tsunami. For example, JMLIT (2015) predicts that detached housing might be partly destroyed in the case of inundation under 2.0 m might be completely destroyed if it exceeds 2.0 m. If detached housing was partly destroyed, consumer durables installed on the first floor might be converted to disaster waste. By contrast, consumer goods on the second floor or above might survive. Although Tabata et al. (2016 and 2017) and Wakabayashi et al. (2017) estimated potential disaster waste generation, they did not consider whether consumer goods are installed on the first storey or higher storeys. Accuracy for the estimation might improve by considering the impact of storeys. This situation is the same for inhabitants who live on the first storey of a housing complex. If they live on the second storey or above in a housing complex, this question could be ignored.

2.2. MIC of consumer goods

The MIC of consumer goods were calculated by using the following methods:

(i) The MIC calculated by Tabata et al. (2016) were utilised. They calculated 18 items of consumer durables, including home appliances and cars, using web-based and statistical surveys. This method was utilised for the consumer durables shown in column (i) of Table 2.

(ii) Based on a calculation by Tabata et al. (2016), the MIC were calculated via the web-based survey. In this method, the average weight of the 20-30 items of the various consumer goods was calculated using websites, such as kakaku.com (2016), which compare and show the prices in different stores, as well as product catalogues. This method was utilised for the consumer durables shown in column (ii) of Table 2.

(iii) This method estimated the MIC using the input-output table (JMIAC 2015a). This method was utilised for the consumer durables shown in column (iii) of Table 2. This method was applied to consumer goods when there were many products of the same kind with different raw materials, and to consumer goods for which it is extremely difficult to obtain weight data as compared with the consumer forwhich the above two methods were adopted.

Table 2 MIC of consumer goods

	Items	MIC [kg/item]	Methods		Items	MIC [kg/USD]*	Methods
(1) Household equipment	1 to 3	27.00	(i)	(6) Furniture	1 to 17	1.03	(iii)
	4	13.50		(8) Interior accessories	1	2.55	(iii)
	5	19.50			2	1.80	
(2) Home appliances	1	4.20	(i)		3	1.02	
	2	5.10	(i)		4	0.89	
	3	61.00	(i)		5 to 7	1.09	
	4	43.00	(i)	(9) Kitchen/household goods	1	0.0019	(iii)
	5	5.50	(i)		2	1.30	
	6	15.00	(ii)		3	20.00	
	7	4.95	(ii)		4 to 6	0.67	
	8	3.35	(ii)		7 and 8	0.33	
	9	3.85	(i)		9	6.63	
	10	5.85	(i)		10	1.60	
	11	7.00	(ii)	(10) Clothes	1 and 2	1.90	(iii)
	12	2.80	(i)	(11) Bags/shoes/umbrella	1 to 3	5.69	(iii)
	13	38.60	(i)		4 and 5	0.077	
	14	13.25	(i)		6	1.44	
	15	27.00	(i)	(12) Education/entertainment goods	1	1.80	(iii)
	16	2.50	(i)		2	2.36	
	17	75.00	(i)		3	4.58	
(3) Air conditioning equipment	1	44.00	(i)		4	6.12E-10	
	2	13.00	(ii)		5	0.26	
	3	2.78	(ii)		6	1.01E-09	
	4	5.60	(ii)		7 to 9	5.12	
	5	7.70	(ii)		10	6.73E-10	
(4) Audio/visual equipment	1	0.29	(i)		11	3.50E-10	
	2	0.25	(ii)	(13) Hairdressing/beauty equipment	1 and 2	1.96E-10	(iii)
	3	0.15	(ii)	(14) Miscellaneous goods	1	2.70	(iii)
	4	2.54	(ii)		2	1.90	
(5) Instruments	1	253.00	(ii)				
	2	31.50					
	3	3.50					
(7) Transportation equipment	1	1,110	(i)				
	2	1,450	(i)				

*Note: 1JPY=0.0088USD (11/8/2017)

	3	82.00	(ii)
	4	131.00	(ii)
	5	21.55	(ii)
	6	6.00	(ii)

2.3. Case study

Disaster waste derived from consumer goods is estimated by the following formulae.

$$W_{\geq 2.0} = S \tag{3}$$

$$W_{>0,<2.0} = \sum_{i=1}^{n} \sum_{x=1}^{n} \sum_{d=1}^{n} \left(\alpha_d P_{d,x}^{i} \times w_d \times F_x^{i} \right) \tag{4}$$

where $W_{\geq 2.0}$ denotes disaster waste derived from consumer goods if inundation depth were 2.0 m or more [in kg];、 $W_{>0,<2.0}$ denotes disaster waste derived from consumer goods if inundation depth were above 0 m and under 2.0m [in kg]; and α is the ratio of consumer goods stored on the first floor [in %].

In this study, two types of formulae were used because the difference in inundation depth affects the degree of housing damage due to the intensity of flood damage based on MLIT (2016 and 2017). In the case of two-storey detached housing, if the flood inundation depth was at a low level, the building damage is restricted to the first floor. This means that, although the consumer goods on the first floor might be converted to disaster waste, the consumer goods on the second floor and above would survive. JMLIT (2016, 2017) sets criteria such that if the inundation depth is above 0 m and under

2.0 m, detached housing is partly destroyed, and if the inundation depth is 2.0 m or more, detached housing is completely destroyed. In this study, these criteria are used to measure the degree of flood damage. In the case of complex housing, it is assumed that only the housing on the first floor is completely destroyed.

The estimated disaster waste derived from the consumer durables is visualised as 500 m grid data using the GIS (JMIAC 2011). Using the GIS, the spatial distribution of disaster waste is easy for local governments to understand. This leads them to discuss concrete measures for disaster waste management.

3. Results and discussions

3.1. Questionnaire survey results

Table A.2 shows results regarding the demographic characteristics of respondents. Regarding the type of housing, this study discusses detached housing and complex housing because quite a few respondents live in miscellaneous type of housing. A Pearson's chi-squared test was conducted to clarify relationships among the demographic characteristics obtained. The results are shown in Table 3. The demographic characteristics confirmed at a significance level of 1 % were ‘annual income of household vs total floor area’, ‘annual income of household vs number in household’, ‘number in household vs total floor area’, and ‘number in household vs type of housing’. There was a tendency for detached housing to be preferred to complex housing when the number in household increased in ‘number in household vs type of housing’.

Table 3 Results of Chi-square test on demographic characteristics

	Chi-square value	Degree of freedom	P value
City vs annual income of household	61.04	49	0.116
City vs total floor area	53.56	49	0.304
Annual income of household vs total floor area	155.68	49	p < 0.001 **
Annual income of household vs number in household	105.85	42	p < 0.001 **
Annual income of household vs type of housing	15.44	14	0.349
Number in household vs total floor area	189.43	42	p < 0.001 **
Number in household vs type of housing	46.40	12	p < 0.001 **
Type of housing vs construction period	13.83	12	0.312

* : P<0.05 ** : P<0.01

Table 4 shows the average possession of consumer goods in a housing unit. Table 5 also shows the average expenditure incurred to possess consumer goods in a housing unit. These results were classified into total floor area and type of housing. Since the questionnaire survey asked for the expenditure incurred to possess each consumer good as a range, the responses were converted into the central value of each range. For example, an answer of ‘4,999 JPY’ was converted to 5,000 JPY, an answer of ‘5,000 JPY to 9,999 JPY’ was converted to 7,500 JPY, an answer of ‘10,000 JPY to 29,999 JPY’ was converted to 20,000 JPY, and an answer of ‘20 million JPY or above’ was converted to 20 million JPY. The results of Table 4 and Table 5 were aggregated for each type of consumer good.

Table 4 Average possession of consumer goods in a housing unit

Type of housing	Total floor area [m^2]	Total	(1) Household equipment	(2) Home appliances	(3) Air conditioning equipment	(4) Audio/visual equipment	(5) Instruments	(7) Transportation equipment
Detached housing	Below 29	35.00	3.00	17.00	6.00	4.00	0.00	5.00
	30to 49	34.29	3.43	14.71	6.29	4.71	0.57	4.57
	50to 59	35.00	2.00	13.50	9.50	5.00	1.50	3.50
	60to 69	35.50	2.50	14.83	6.50	5.33	1.67	4.67
	70to 79	42.55	3.45	18.73	8.73	6.64	1.45	3.55
	80to 99	39.15	3.31	17.42	9.27	5.62	0.46	3.08
	100 or above	41.07	3.90	17.38	9.02	6.14	1.31	3.31
	Average	37.51	3.09	16.23	7.90	5.35	0.99	3.95
Complex housing	Below 29	16.82	1.85	9.15	2.36	2.61	0.30	0.55
	30to 49	22.90	2.36	11.18	4.13	3.64	0.28	1.31
	50to 59	27.36	2.76	12.67	5.12	4.21	0.61	2.00
	60to 69	32.00	2.57	14.05	6.57	5.49	0.68	2.65
	70to 79	34.89	3.16	16.65	6.32	5.38	0.86	2.51
	80to 99	33.45	2.59	15.17	7.03	5.07	0.90	2.69
	100 or above	33.08	3.38	14.31	6.92	4.69	1.00	2.77
	Average	28.64	2.67	13.31	5.49	4.44	0.66	2.07

Unit：items/housing

Table 5 Average expenditure incurred to purchase consumer goods in a housing unit

Type of housing	Total floor area [m^2]	Total	(6) Furniture	(8) Interior accessories	(9) Kitchen/household goods	(10) Clothes	(11) Bags/shoes/umbrella	(12) Education/entertainment goods	(13) Hairdressing/beauty equipment	(14) Miscellaneous goods
Detached housing	Below 29	6,530	572	726	901	264	1,077	2,946	44	0
	30to 49	21,766	11,433	1,591	1,220	452	1,304	3,326	198	2,243
	50to 59	7,773	6,047	275	264	132	726	330	0	0
	60to 69	16,256	2,482	1,909	542	678	1,685	5,462	191	3,307
	70to 79	26,614	10,087	2,255	1,191	1,853	1,857	4,675	271	4,424
	80to 99	29,974	7,592	2,280	1,200	1,686	3,636	6,740	1,006	5,834
	100 or above	42,231	12,590	4,202	2,814	1,746	4,279	6,051	372	10,175
	Average	21,592	7,257	1,891	1,162	973	2,081	4,219	297	3,712
Complex housing	Below 29	17,169	1,903	530	485	4,691	2,271	4,662	153	2,474
	30to 49	14,077	4,029	690	654	652	1,267	3,170	265	3,351
	50to 59	28,958	4,117	1,012	1,173	1,803	2,255	13,001	316	5,280
	60to 69	28,270	7,604	2,279	1,369	1,755	3,098	6,236	429	5,500
	70to 79	34,286	11,817	2,838	1,321	2,111	2,961	6,368	611	6,260
	80to 99	38,367	10,679	2,633	1,949	4,388	5,080	6,738	393	6,506
	100 or above	26,083	12,759	2,484	1,985	777	2,190	2,907	299	2,682
	Average	26,744	7,558	1,781	1,276	2,311	2,732	6,155	352	4,579

Unit：USD/housing

Note: 1JPY=0.0088USD (11/8/2017)

The results showed that the average possession of consumer goods of types (1) through (5) and (7) in housing totalled 37.51 items in detached housing and 28.64 items in complex housing. The average expenditure to possess consumer goods of types (5) and (8) through (14) in housing was 21,592 USD in detached housing and 26,744 USD in complex housing. For both types of housing, the average possession of the consumer goods and the average expenditure to possess the consumer goods tended to increase as total floor area increased.

Table 6 shows the percentage of consumer goods installed on the first floor. This result is for detached housing only except for the goods of type (7). As a result, the figure for the following types of consumer goods exceeded 70 %: (1) household equipment, (7) transportation equipment, (9) kitchen/consumer goods, and (13) hairdressing/beauty equipment. By contrast, consumer goods such as (6) furniture and (10) clothes were at a low percentage level. This result is reasonable because living and kitchen spaces are installed on the first floor and bedrooms and closets are installed on the second floor or above in typical Japanese detached housing with two or more storeys.

Table 6 Percentage of consumer goods installed on the first floor (Detached housing only except for type (7))

Total floor area [m^2]	(1) Household equipment	(2) Home appliances	(3) Air conditioning equipment	(4) Audio/visual equipment	(5) Instruments	(6) Furniture	(7) Transportation equipment	
							Detached housing	Complex housing
Below 29	67%	53%	50%	25%	-	0%	-	100%
30to 49	71%	59%	37%	50%	17%	77%	100%	100%
50to 59	100%	86%	48%	79%	100%	-	100%	100%
60to 69	78%	64%	50%	68%	33%	0%	100%	100%
70to 79	70%	63%	51%	55%	71%	28%	100%	99%
80to 99	64%	62%	41%	54%	39%	31%	100%	99%
100 or above	73%	71%	52%	66%	61%	62%	100%	92%
Average	75%	65%	47%	56%	50%	36%	100%	99%

Total floor area [m^2]	(8) Interior accessories	(9) Kitchen/household goods	(10) Clothes	(11) Bags/shoes/umbrella	(12) Education/entertainment goods	(13) Hairdressing/beauty equipment	(14) Miscellaneous goods
Below 29	-	-	-	-	-	-	-
30to 49	39%	72%	27%	68%	32%	67%	25%
50to 59	-	-	-	-	-	-	-
60to 69	-	-	-	-	-	-	-
70to 79	29%	58%	2%	49%	33%	67%	23%
80to 99	43%	73%	25%	60%	34%	73%	55%
100 or above	45%	78%	30%	55%	50%	71%	43%
Average	44%	75%	27%	62%	41%	72%	40%

3.2. Micro material stock derived from consumer goods

Figure 1 and Table A.3 show the average micro material stock derived from consumer goods in housing. As a result, the micro material stock derived from consumer goods in housing totalled 5.84 t in detached housing and 5.71 t in complex housing. Thus, micro material stock in detached housing is greater than that in complex housing.

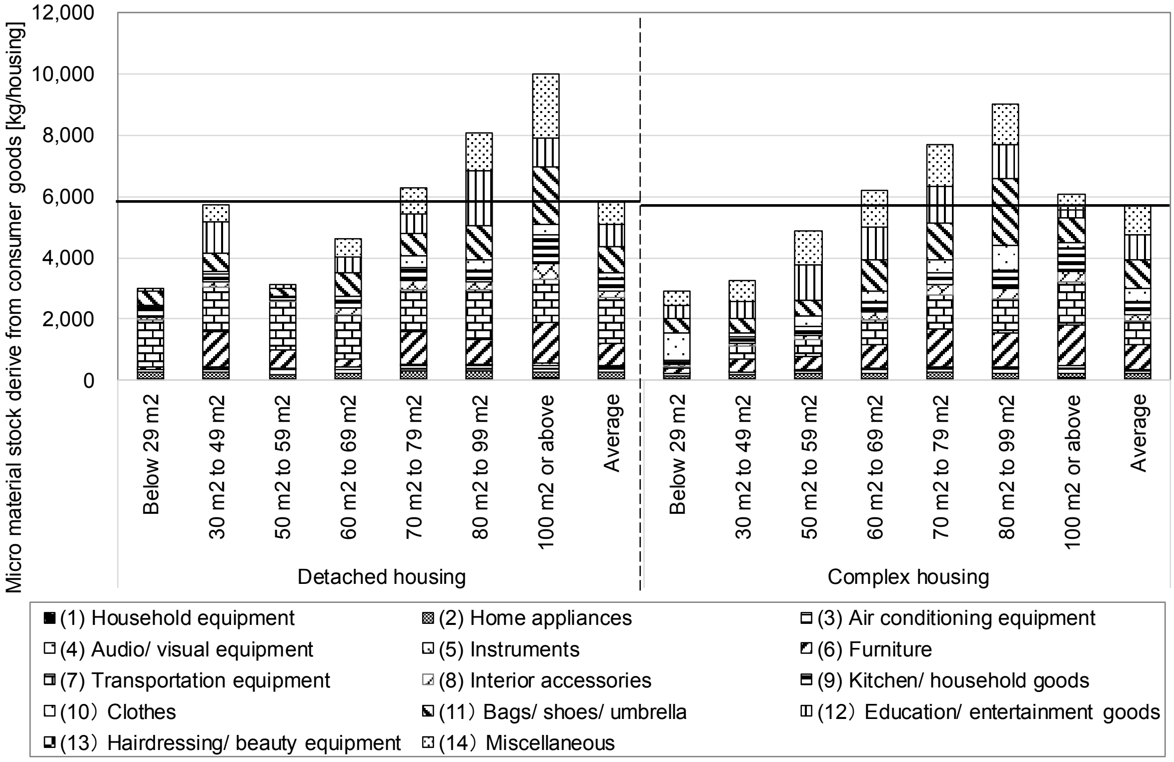


Figure 1 Average micro material stock derived from consumer goods in a housing unit

A comparison of macro material stock derived from housing with the micro material stock derived from consumer goods was conducted to examine the impact of micro material stock. The average total floor area of detached housing in Tokyo and

Kanagawa prefecture is 110m^2 (JMIAC 2015b). The material intensity coefficient of macro material stock including building and foundation is 488 kg per m^2 of floor area in detached housing (Tanikawa et al. 2014). The macro material stock derived from detached housing tis 53.7 t, calculated by multiplying the total floor area by the MIC. This comparison shows that the micro material stock derived from consumer goods corresponds to 10.9 % of the macro material stock derived from detached housing. Schiller et al. (2017) found that the micro material stock derived from consumer goods corresponds to only 0.46 % of the macro material stock derived from building. However, this study focused on residential and non-residential buildings to estimate the anthropogenic stock in the area. Therefore, it did not consider the comparison between macro material stock and micro material stock regarding housing. This study found that the micro material stock derived from consumer goods is low, but the amount stocked in housing cannot be ignored.

Another result is that the micro material stock derived from consumer goods in detached housing with total floor area of 100 m^2 or more was 3.4 times higher than that of detached housing with total floor area less than 29 m^2 . In the case of complex housing, the difference was 2.1 times. The micro material stock derived from consumer goods increased according to an increase in total floor area. (7) transportation equipment was dominant in the micro material stock derived from consumer goods, and this material stock did not vary with an increase in the total floor area. (6) furniture, (11) bags/shoes/umbrella, and (14) miscellaneous goods tended to increase as total floor area increased. It was not known why the micro material stock derived from consumer goods in detached housing with total floor area of 30–49 m^2 of was larger than the results for other floor areas. Respondents in this case had a high annual household income, despite the small floor area. This might have affect the result.

3.3. Sensitivity analysis

To examine the reliability and validity of the above-mentioned result regarding micro material stock derived from consumer goods, it is important to investigate the usability of methods of this study. However, direct comparison is extremely difficult because there is no related data on the micro material stock derived from the consumer goods in housing. Thus, the following two types of sensitivity analysis were conducted for indirect comparison. One of them examined reliability of the questionnaire results by comparing the possession data that acquired by the questionnaire survey and the national statistical data regarding possession, by referring to Gontia et al. (2018), Liang et al. (2017) and Schiller et al. (2017). The other examined the validity of the calculated MIC for the estimation by calculating elasticity. It considered the impact for the micro material stock if the values of MIC were changed by referring to Jochem et al. (2016), Rapson (2014), and Zhang et al. (2017).

First, the validity of the questionnaire results regarding goods of types (1) through (5) and (7) was examined by comparing them to similar results published as national statistical data. The average possession of consumer goods in housing was also investigated in the ‘National survey of family income and expenditure (JMIAC2011)’. From this statistical data it is possible to grasp the average data of all cities and towns in Tokyo or Kanagawa Prefecture although data for each city or town has not been released. Figure 2 shows the result of a comparison between the questionnaire survey and statistical data regarding the average possession of the different types of consumer good. If the circle representing the consumer goods is is plotted in a straight line that is at an angle of 45 degrees to origin, the owned quantity for it is perfectly matched with the results of the questionnaire survey and statistical data. Although the questionnaire survey and statistical data matched, most of the consumer goods were close to the straight line because the survey area was not similar. There was a difference between the two data sources for some consumer goods, such as personal computers, flat TV sets, and stereo sets. The questionnaire survey results were generally considered to be close to the results of the statistical data. The results of the questionnaire survey can be confirmed to be reliable for the estimation.

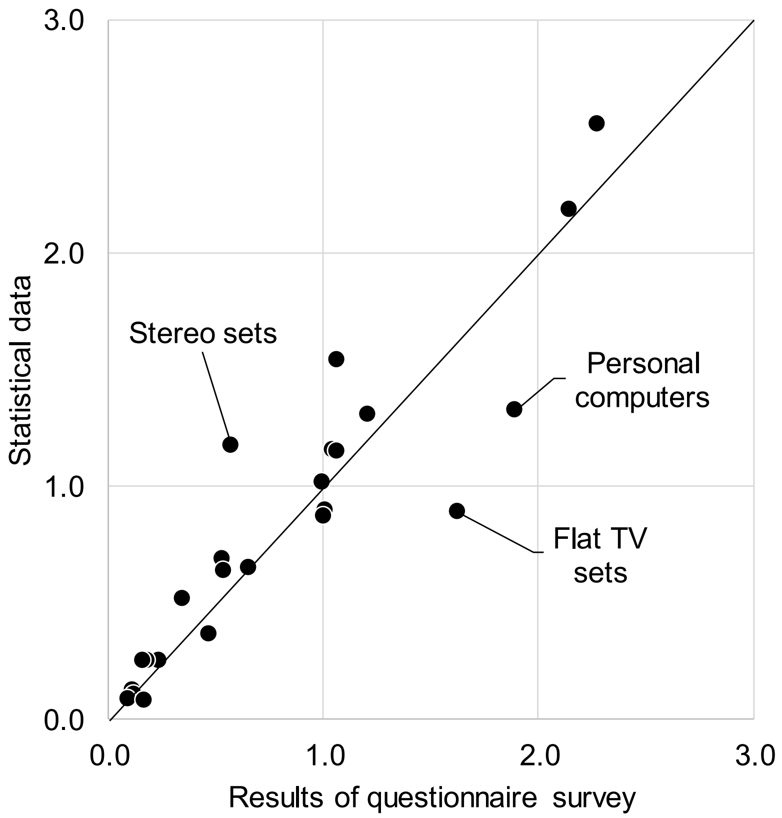


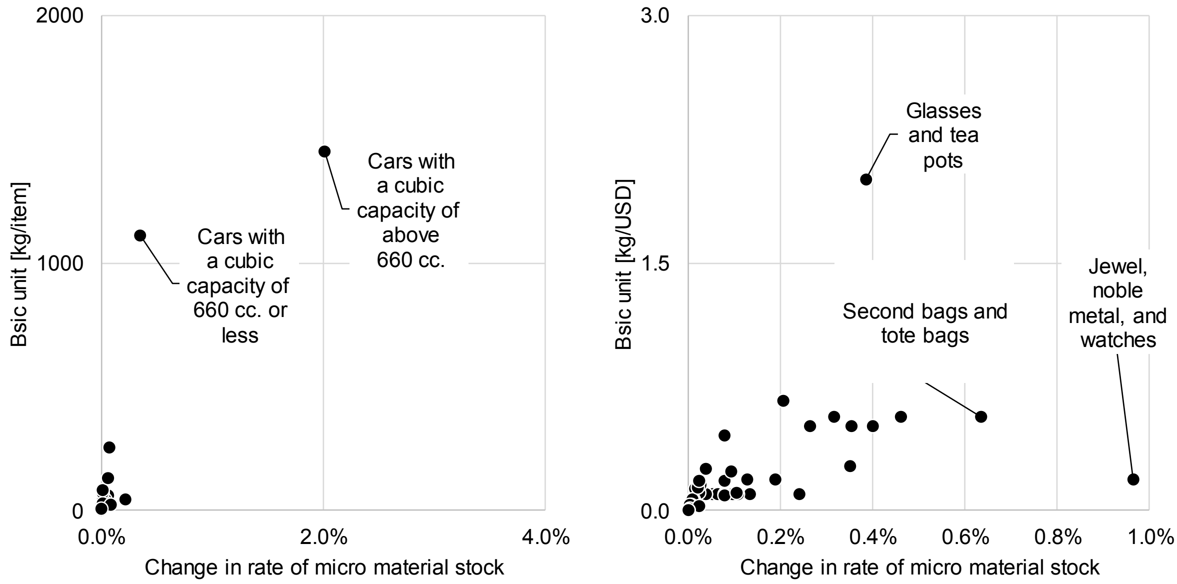
Figure 2 Comparison between questionnaire survey and statistical data regarding average possession of various consumer goods

Subsequently, we examined which consumer goods would have a major impact on the results of the micro material stock by investigating the rate of change in micro material stock derived from consumer goods per housing unit when the MIC changed. The rate of change in micro material stock derived from consumer goods per housing unit was calculated with the following formula. This formula was creating basing on a thinking of price elasticity of demand. For the investigation, the changing rate was observed when the MIC of the consumer durables varied by up to 10%.

$$c = \frac{\Delta s_{d,x}^{i}}{s_{d,x}^{i}} \times 100 \quad (5)$$

where *c*: changing rate [%].

Figure 3 shows the result of the relationship between the MIC and the micro material stock derived from consumer goods per housing unit. As a result, ‘cars with a cubic capacity of above 660 cc’ was the consumer good with a major impact on all the consumer goods. These consumer goods have the greatest basic value, and 10 % of the change of the MIC corresponded to 2 % of the impact for all micro material stock derived from consumer goods in housing. ‘Glasses and teapots’, ‘second bags and tote bags’, and ‘jewel, noble metal, and watches’ were also affected by 0.5 % to 1.0 % of the impact for all micro material stock derived from consumer goods in housing. However, the maximum impact of changing the MIC is 2.0 %. Fetter and Rakes (2012) and Tajima et al. (2014) indicate that estimated debris volume by prediction model has margin of error within a 30 %. Although increasing accuracy of the prediction model is like an eternal task, calculated impact in this sensitivity analysis was quite small comparing with the margin of error and it is negligible. The results of the estimated MIC can be confirmed to be valid for the estimation.



(a) Types (1) to (5) and (7)   (b) Types (6) and (8) to (14)

Figure 3 Relationship between the MIC and the micro material stock derived from consumer goods per housing unit

3.4. Case study at Kawasaki City

Figure 4, Figure 5, and Figure 6 show spatial distributions of housing, the micro material stock derived from consumer goods, and the disaster waste derived from consumer goods, respectively, by visualising with Google Earth. The area of each grid is 0.25 m^2. The number of households in Kawasaki City was 673,630 (detached housing: 192,103; complex housing: 481,527). The estimated micro material stock derived from consumer goods was 3,667,000 t. The area on the east coast and along Tama river had more micro material stock than the other areas. The estimated potential disaster waste derived from consumer goods was 229,000 t if a hazard map of each grid divided by flood damage was assumed. The predicted amount corresponds to 49 % of the municipal solid waste in Kawasaki City in 2014 (JMOE 2017b).

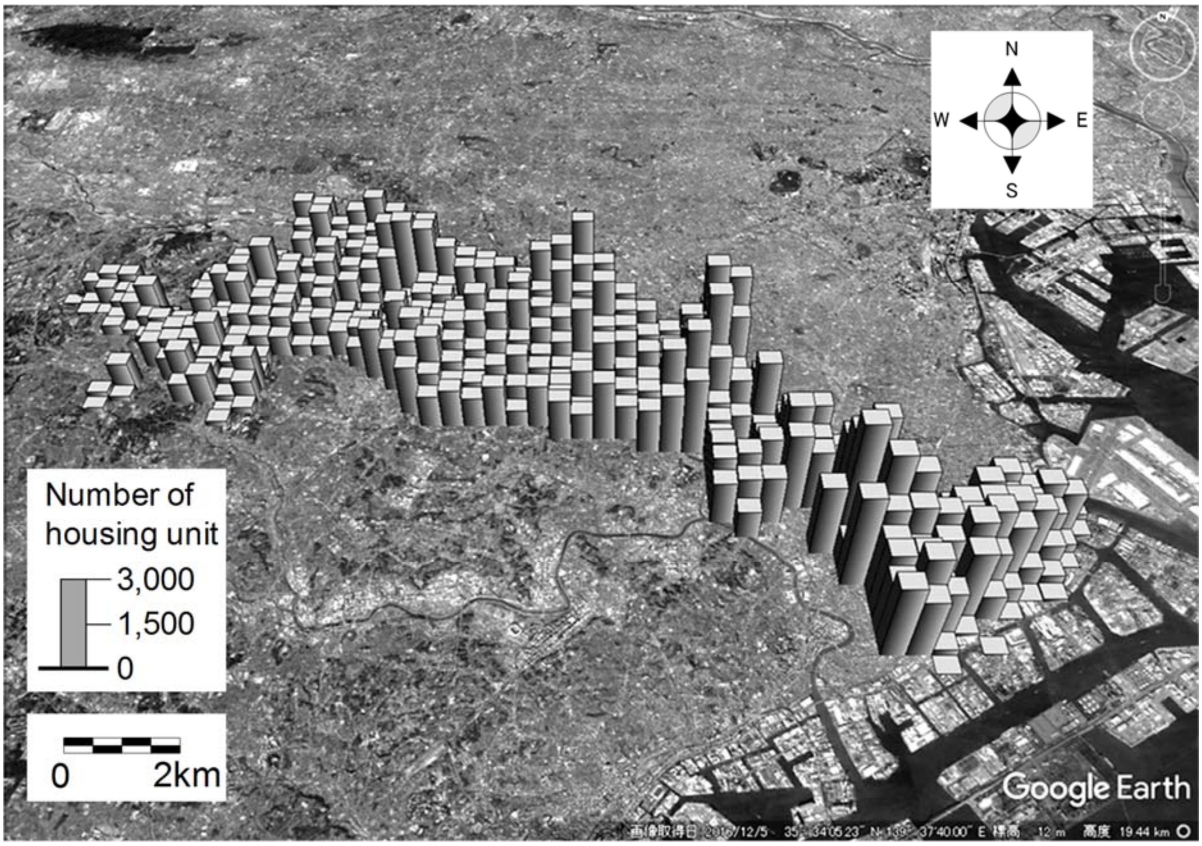


Figure 4 Spatial distribution of housing

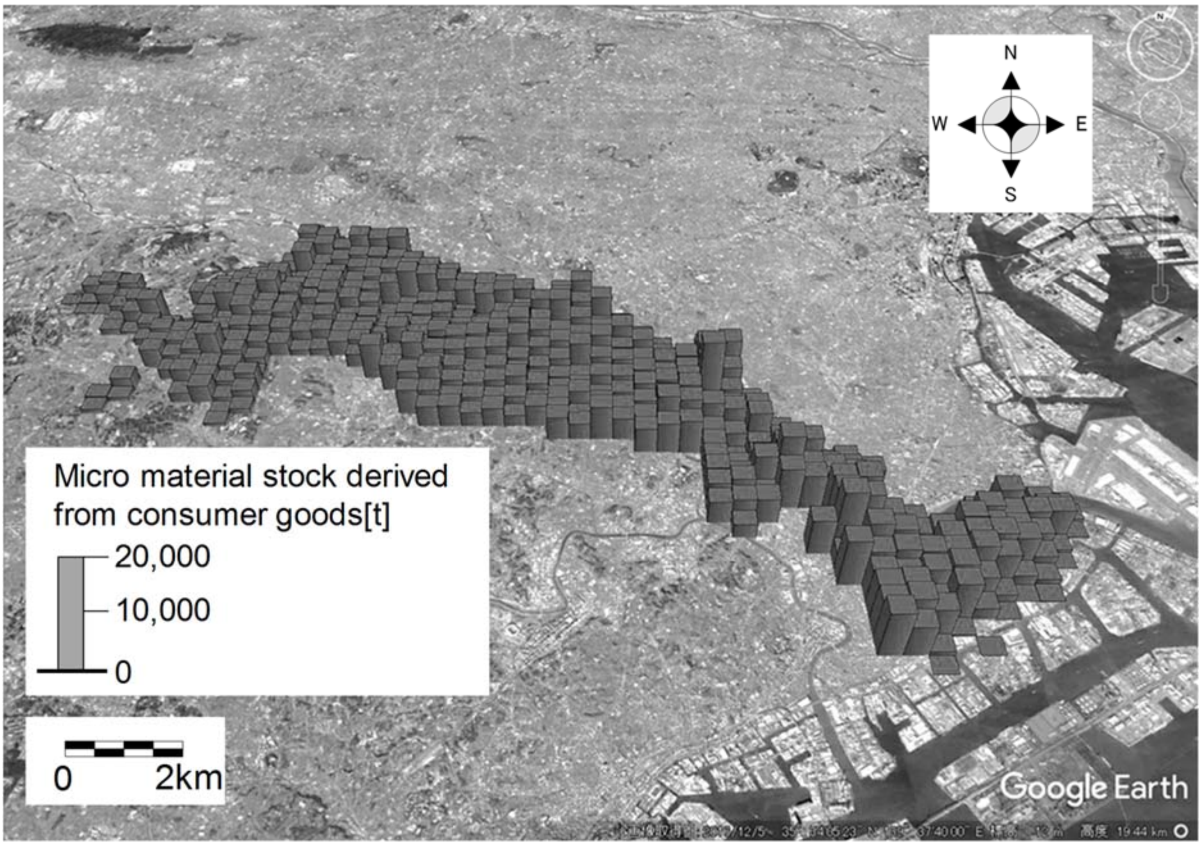


Figure 5 Spatial distribution of micro material stock derived from consumer goods

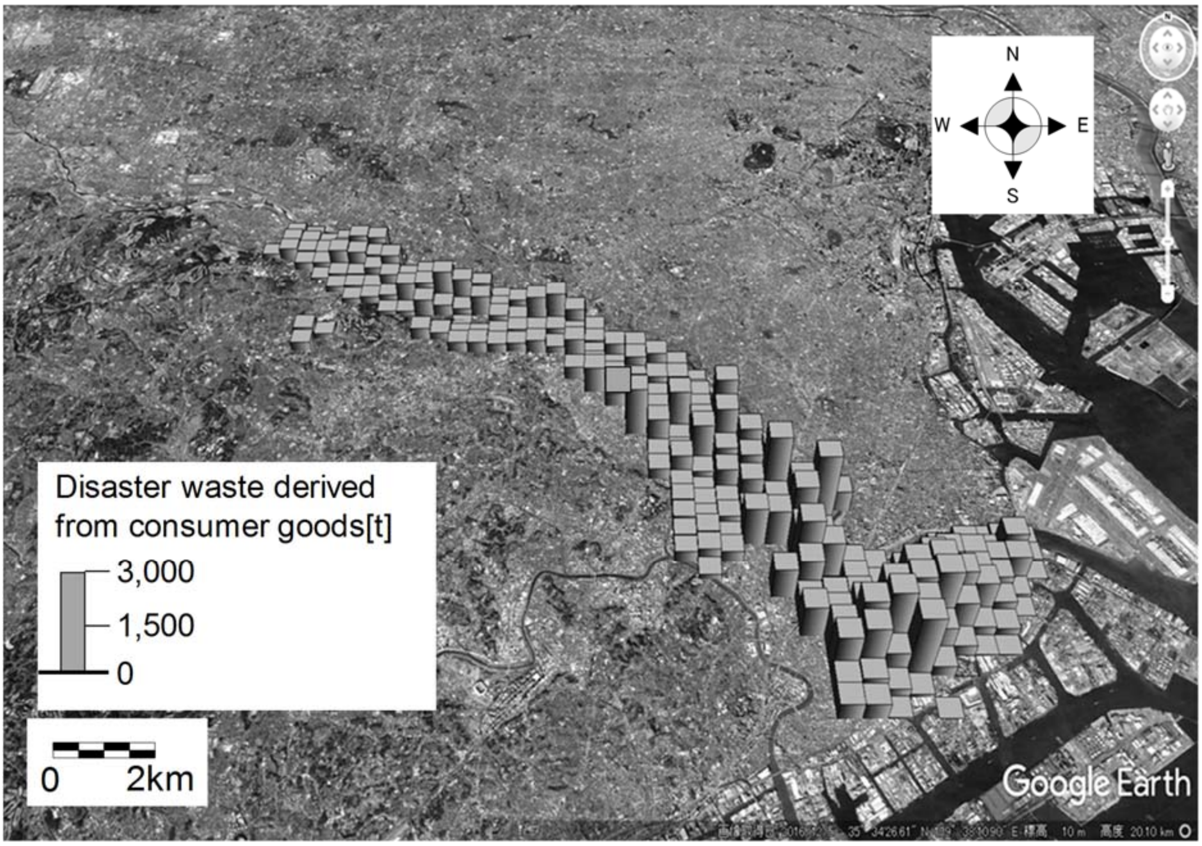


Figure 6 Spatial distribution of disaster waste derived from consumer goods

The above potential disaster waste was estimated using formulas (3) and (4), considering the storeys on which the consumer goods are installed. This result means that the estimation considers each grid of the inundation depth. If the estimation did not consider the storeys on which the consumer goods are installed, then only formula (3) is used because it assumes that all the consumer goods are converted to disaster waste regardless of the inundation depth. The disaster waste derived from consumer goods then increased to 317 thousand t. This estimation is 0.72 times bigger than the result that considered the storeys on which the consumer goods are installed. This result indicates that overestimation might occur if the storeys on which the consumer goods are installed are not considered. The suggestion obtained in this study might provide useful information to investigate how to estimate potential disaster waste for local governments.

4. Conclusions and outlook

This study estimated the micro material stock in housing. Possession and weight data for various consumer goods were clarified to estimate the micro material stock by using a web-based questionnaire and statistical surveys. Fourteen types of consumer goods, covering 97 items, were identified in the survey; the goods included household equipment, home appliances, cars, interior accessories, and clothes to understand as much as possible the different types of micro material stock in housing. The disaster waste derived from consumer goods was also estimated based on the micro material stock.

The following conclusions can be drawn:

(1) Various types of consumer goods were identified to clarify the micro material stock in housing in the questionnaire survey. The average possession of consumer goods of types (1) household equipment, (2) home appliances, (3) air conditioning equipment, (4) audio/visual equipment, (5) instruments, and (7) transportation equipment in a housing unit totalled 37.51 items in detached housing and 28.64 items in complex housing. The average expenditure incurred to possess consumer goods of types (6) furniture, (8) interior accessories, (9) kitchen/consumer goods, (10) clothes, (11)

bags/shoes/umbrella, (12) education/entertainment goods, (13) hairdressing/beauty equipment, and (14) miscellaneous goods in a housing unit totalled 21,592 USD in detached housing and 26,744 USD in complex housing.

(2) Micro material stock derived from consumer goods in housing totalled 5.84 t in detached housing and 5.71 t in complex housing. Micro material stock in detached housing is greater than that in complex housing. The micro material stock derived from consumer goods in detached housing with 100 m^2 or more of total floor area was 3.4 times higher than that of detached housing with less than 29 m^2 of total floor area.

(3) The estimated micro material stock derived from consumer goods totalled 3,667,000 t in Kawasaki City, considering the number of households and micro material stock of each grid. The estimated potential disaster waste derived from consumer goods totalled 229,000 t when the inundation depth by flood damage was considered. The estimation result that did not consider the storeys on which consumer goods were installed was 0.72 times larger than the result which considered the storeys on which consumer goods were installed. Although most previous studies do not consider the storeys of housing, this result indicates that overestimation might occur if the storeys of housing are not considered.

When local governments discuss disaster waste management considering future natural disasters, the starting point is estimation of the potential disaster waste (Brown et al. (2011) and Tabata et al. (2017)). Although improvement of accuracy regarding the MIC is required, data on possession and weight of various consumer goods that this study obtained should be fundamental data in estimating potential disaster waste. This study also clarified the storeys on which consumer goods are installed. Methods that this study proposed are simple and have broad utility; they can be applied in both developed and developing countries. Once local governments use our data on the possession of consumer goods in housing and the MIC, they can estimate the micro material stock derived from consumer goods in their area. If they conduct survey on possession of consumer goods in housing, they can also estimate the micro material stock using the MIC, which is the result of this study. The potential disaster waste can also be estimated by considering the prediction about the degree of housing damage in their area.

The prevention of the occurrence of disaster waste might be discussed to estimate the potential disaster waste. The occurrence of natural disasters cannot be stopped, so thinking about their prevention is impossible. However, damage from earthquake can be prevented by promoting earthquake-resistant buildings. Such measures also lead to the reduction of disaster waste. Consumer goods can also be made earthquake-resistant; for example, furniture can be made earthquake-resistant by fixing it to the wall with screws. In another case, letting go of consumer goods that are not needed might lead to the prevention of disaster waste. For example, heating equipment is required in the winter season, but not in other seasons. It is stored in an external shed after the winter season. In another case, 32.8 % of consumers who possess cars do not drive them on weekdays (JMLIT 2011). For a long time, people in the world of marketing have said that ‘people do not want to buy a quarter-inch drill, they want a quarter-inch hole. People might only use an electric drill a few times, unless it is used for a hobby. However, they own an electric drill even though they use it seldom. Based on the circular economy, sharing the functions of consumer goods via rental or sharing should be prioritised over owning goods. Sharing consumer goods might lead to a reduction in the possession of such goods in housing and a reduction in the disaster waste derived from consumer goods. Preventing disaster waste also leads to reduction of the environmental burden and treatment cost of disaster waste. Therefore, thinking of the circular economy is also effective in reducing disaster waste. Thus, local governments and researchers should discuss not only disaster waste management but also prevention of disaster waste.

Acknowledgments

This study was partly supported by the Japan Construction Information Center Foundation.

References

Brown, C., Milke, M., Seville, E., 2011. Disaster waste management: A review article. Waste Manag. 31, 1085–1098.

Chen, W. Q., Graedel, T. E., 2015. In–use product stocks link manufactured capital to natural capital. *PNAS.* 112, 6265–6270.

Eisenmenger, N., Wiedenhofer, D., Schaffartzik, A., Giljum, S., Bruckner, M., Schandl, H., Wiedmann, T. O., Lenzen, M., Tukker, A., Koning, A., 2016.Consumption–based material flow indicators — Comparing six ways of calculating the Austrian raw material consumption providing six results. Ecol. Econ. 128, 177–185.

European Commission, 2017. European Circular Economy Stakeholder Platform. http://ec.europa.eu/environment/circular–economy/ (accessed 8 November 2017)

Fetter, G., Rakes, T., 2012. Incorporating recycling into post-disaster debris disposal. Socio. Econ. Plan. Sci., 46, 14–22.

Fujie, K., Goto, N., Usui, T., 2001. A method to evaluate regional material flow for designing recycling society. Proc EcoDesign, 974–9.

Gontia, P., Nägeli, C., Rosado, L., Kalmykova, Y., Österbring, M, 2018. Material-intensity database of residential buildings: A case-study of Sweden in the international context. Resour. Conserv. Recycl. 130, 228–239.

He, F., Zhung, J., 2016. Balancing pre–disaster preparedness and post–disaster relief. Eur. J. Oper. Res. 252, 246–256.

Hirayama, N., Kawata, Y., 2005. Estimation Procedure for Quantity of Disaster Waste from the Viewpoint of Emergency Responses of Public Authorities at Flood Disaster. Environ. Sys. Res. 33,29–36. [in Japanese]

Hirayama, N., Kawata, Y., Suzuki, S., Harada, K., 2009. Estimation Procedure for Potential Quantity of Tsunami Debris on Tsunami Earthquake Disasters. Proc. Twelfth Int. Waste

Manag. Landfill Symp. CD–ROM.

Hu, Z. H., Sheu, J. B., 2013. Post-disaster debris reverse logistics management under psychological cost minimization. Transport. Res. B-Meth., 55, 118–414.

Inaba, T., Tabata, T., Tsai, P., 2017. Development of a basic rate of household energy consumption considering usage time and quantity of consumer durables. J. Sustain. Dev. Energy Water Env. Syst. 5, 533–545.

Japan Central Disaster Management Council, 2014. Basic disaster prevention plan. http://www.bousai.go.jp/taisaku/keikaku/pdf/kihon_basic_plan.pdf (accessed 8 November 2017)

Japan Ministry of Environment (JMOE), 2008.3R initiative. https://www.env.go.jp/recycle/3r/initiative/en/ (accessed 8 November 2017)

JMOE, 2014. Disaster Waste Countermeasure Guidelines. http://kouikishori.env.go.jp/action/investigative_commission/summary/h26/pdf/h2603report.pdf (accessed 8 November 2017) [in Japanese]

JMOE, 2017a. Recycling of disaster waste. http://kouikishori.env.go.jp/archive/h23_shinsai/implementation/recycling/ (accessed 8 November 2017)

JMOE, 2017b. MSW treatment statistics in Japan. http://www.env.go.jp/recycle/waste_tech/ippan/stats.html (accessed 8 November 2017)

Japan Ministry of Internal Affairs and Communications (JMIAC), 2011. 2009 National survey of family income and expenditure. http://www.stat.go.jp/data/zensho/2009/ (accessed 8 November 2017)

JMIAC, 2012. 2010 National census.

JMIAC, 2015a. 2011 Input–Output table. http://www.soumu.go.jp/toukei_toukatsu/data/io/ (accessed 8 November 2017)

JMIAC, 2015b. 2013 Housing and land survey of Japan. http://www.stat.go.jp/data/jyutaku/index.htm (accessed 8 November 2017)

Japan Ministry of Land, Infrastructure and Transport (JMLIT), 2015. Manual for flood control from the viewpoint of economy. https://www.mlit.go.jp/river/basic_info/seisaku_hyouka/gaiyou/hyouka/h1704/chisui.pdf (accessed 8 November 2017)

JMLIT, 2011. The 5th Nationwide Person Trip Survey in 2010. http://www.mlit.go.jp/toshi/tosiko/ (accessed 8 November 2017)

JMLIT, 2015. 2013 Housing and land survey of Japan. http://www.stat.go.jp/data/jyutaku/ (accessed 2 February 2018)

JMLIT, 2016. Hazard map for flood damage at Tama River, Asa River and Okuri River. http://www.ktr.mlit.go.jp/keihin/keihin00194.html (accessed 8 November 2017)

JMLIT, 2017. National Land Numerical Information download service. http://nlftp.mlit.go.jp/ksj/gml/datalist/KsjTmplt–A31.html (accessed 8 November 2017)

Jochem, D., Janzen, N., Weimar, H., 2016. Estimation of own and cross price elasticities of demand for wood-based products and associated substitutes in the German construction sector. J. Clean. Prod. 137, 1216–1227.

Jones, R. V., Fuertes, A., Lomas, K. L., 2015. The socio-economic, dwelling and appliance related factors affecting electricity consumption in domestic buildings. Renew. Sust. Energ. Rev. 43, 901–917.

Kakaku.com, 2017. Kakaku.com. http://kakaku.com (accessed 8 November 2017)

Kung, H.Y., Chen, C.H., Ku, H.H., 2012. Designing intelligent disaster prediction models and systems for debris–flow disasters in Taiwan. Expert. Syst. Appl. 39, 5838–5856.

López, L. A., Arce, G., Morenate, M., Zafrilla, J.E., 2017. How does income redistribution affect households' material footprint?. J. Clean. Prod. 153, 515–527.

Lau, W. K. Y., Chung, S. S., Zhang, C., 2013. A material flow analysis on current electrical and electronic waste disposal from Hong Kong households. Waste Manag. 33, 714–721.

Liang, H., Dong, L., Tanikawa, H., Zhang, N., Gao, Z., Luo, X., 2017. Feasibility of a new-generation nighttime light data for estimating in-use steel stock of buildings and civil engineering infrastructures. Resour. Conserv. Recycl. 123, 11–23.

Maryono, Nakayama, H., & Shimaoka, T., 2015. Identification of factors affecting stakeholders' intentions to promote preparedness in disaster waste management: A structural equation modeling approach. Memoirs. Fac. Eng. Kyushu. Univ., 74, 79-98

Miatto, A., Schandl, H., Tanikawa, H., 2017. How important are realistic building lifespan assumptions for material stock and demolition waste accounts?. Resour. Conserv. Recycl. 122, 143–154.

Nakayama, H., Shimaoka, T., Omine, K., Maryono, Patsaraporn, P., Siriratpiriya, O., 2013. Solid waste management in Bangkok at 2011 Thailand floods. J. Dis. Res. 456-464

Nassar, N. T., 2017. Shifts and trends in the global anthropogenic stocks and flows of tantalum. Resour. Conserv. Recycl. 125, 233–250.

Oguchi, M., Kameya, T., Yagi, S., Urano, K., 2008. Product flow analysis of various consumer durables in Japan. Resour. Conserv. Recycl. 52, 463–480.

Rapson, D., 2014. Durable goods and long-run electricity demand: Evidence from air conditioner purchase behaviour. J. Environ. Econ. Manag. 68, 141–160.

Rincón, L., Pérez, G., Cabeza, L.F., 2013. Service life of the dwelling stock in Spain. Int. J. Life Cycle Assess., 18, 919–925.

Schaffartzik, A., Eisenmenger, N., Krausmann, F., Weisz, H., 2013. Consumption–based Material Flow Accounting: Austrian Trade and Consumption in Raw Material Equivalents 1995–2007. Ind. Ecol. 18, 102–112.

Schebek, L., Schnitzer, B., Blesinger, D., Köhn, A., Miekley, B., Linke, H. J., Lohmann, A., Motzko, C., Seemann, A., 2017. Material stocks of the non-residential building sector: the case of the Rhine-Main area. Resour. Conserv. Recycl. 123, 24–36.

Schiller, G., Müller, F., Ortlepp, R., 2017. Mapping the anthropogenic stock in Germany:

Metabolic evidence for a circular economy. Resour. Conserv. Recycl. 123, 93–107.

Stephan, A., Athanassiadis, A., 2017. Quantifying and mapping embodied environmental requirements ofurban building stocks. Build. Environ. 114, 187–202.

Stolle, A., Langer, M., Blöthe, J.H., Korup, O., 2015. On predicting debris flows in arid mountain belts. Glob. Planet Change. 126, 1–13.

Tabata, T., Zhang, O., Yamanaka, Y., Tsai, P., 2016. Estimating potential disaster waste generation for pre–disaster waste management. Clean Technol. Envir. 18, 1735–1744.

Tabata, T., Wakabayashi, Y., Tsai, P., Saeki, T., 2017. Environmental and economic evaluation of pre–disaster plans for disaster waste management: Case study of Minami–Ise, Japan. Waste Manag. 61, 386–396.

Tajima, R., Hirayama, N., Osako, M., 2014. Theory and practice of pre-disaster planning for disaster waste management. Soc. Sci. Manag. Syst. Int. J., 9, 1–12.

Takatsuki, H., Sakai, S., Mizutani, S., 1995. Disasters and State of Waste, Generation Basic Units of Disaster Waste and Change of Constitution of Normal Waste. J. Japan Soc. Mater. Cycles Waste Manag. 6, 351–359. [in Japanese]

Tanikawa, H., Managi, S., Lwin, C. M., 2014. Estimates of lost material stock of buildings and roads due to the Great East Japan Earthquake and tsunami. Ind. Ecol. 18, 421–431.

Tansel, B., 2017. From electronic consumer products to e–wastes: Global outlook, waste quantities, recycling challenges. Environ. Int. 98, 35–45.

Wakabayashi, Y., Tsai, P., Tabata, T., Saeki, T., 2017. Life cycle assessment and life cycle costs for pre–disaster waste management systems. Waste Manag. 68, 688–700.

Xiao, J., Xie, H., Zhang, C., 2012. Investigation on building waste and reclaim in Wenchuan earthquake disaster area. Resour. Conserv. Recycl. 61, 109–117.

Zhang, C., Chen, W. Q., Liu, G., Zhu, D. J., 2017. Economic Growth and the Evolution of Material Cycles: An Analytical Framework Integrating Material Flow and Stock Indicators. Ecol. Econ., 140, 265–274.

Appendices

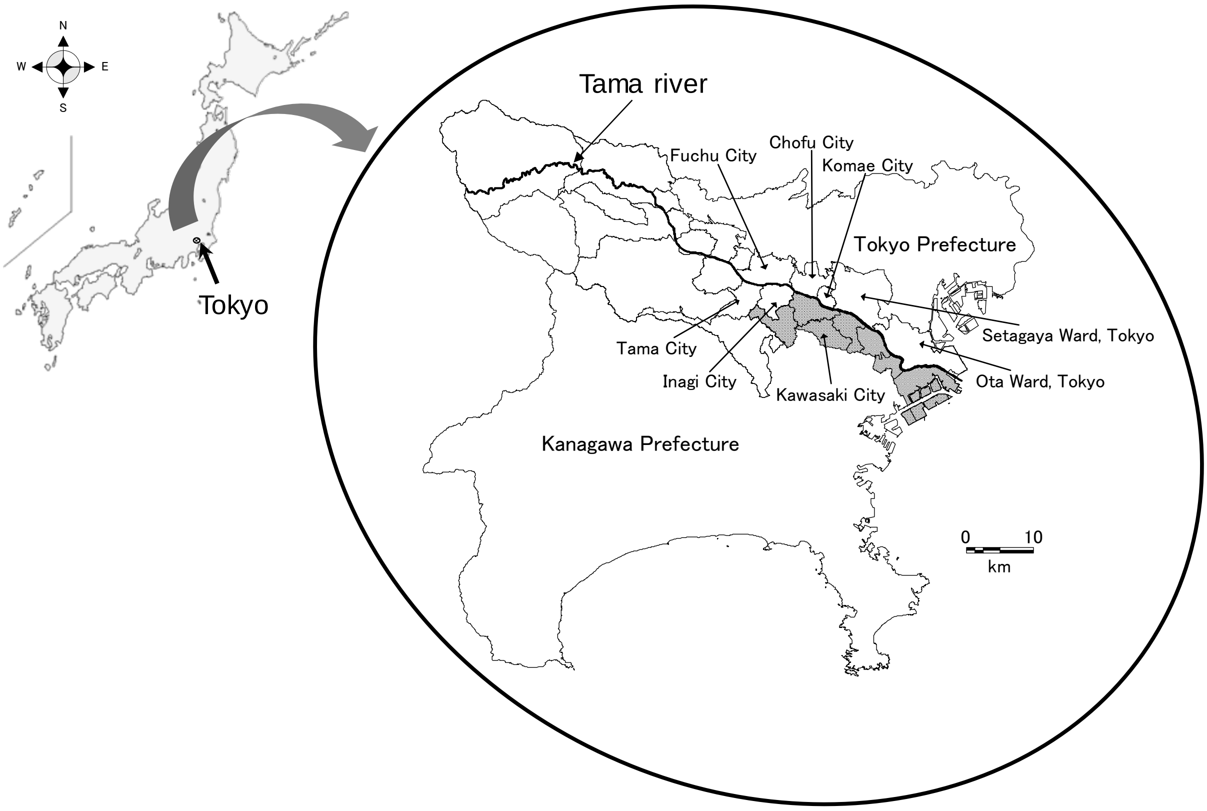


Figure A.1 Location of the case study area

Table A.1 Targeted consumer goods

(1) Household equipment (5 items)	(1)-1. Electric water heaters, (1)-2. Gas water heaters, (1)-3. Petroleum water heaters, (1)-4. Gas stoves and IH cooking heaters, and (1)-5. Warm water washing toilet seats
(2) Home appliances (17 items)	(2)-1. Vacuum cleaner, (2)-2. Refrigerators, (2)-3. Drum type washing machines,(2)-4. Washing machines excluding drum type washing machines, (2)-5. Dishwashers, (2)-6. Microwave ovens, (2)-7. Electric cookers excluding microwave oven, (2)-8. Electric pots and coffee makers, (2)-9. Juicers and food processors, (2)-10. Rice cookers, (2)-11. Sewing machines, (2)-12. Stereo sets, (2)-13. CRT TV sets, (2)-14. Flat TV sets, (2)-15. Video recorders, (2)-16. Personal computers, and (2)-17. Electric massage chairs
(3) Air conditioning equipment (5 items)	(3)-1. Air conditioners, (3)-2. Kotatsu (table with electric heater), (3)-3. Cooling equipment, 3)-4. Heating equipment, and (3)-5. Air purifiers
(4) Audio/visual equipment (4 items)	(4)-1. Cameras, (4)-2. Video cameras, (4)-3. Smart phones and mobile phones, and (4)-4. Fixed telephone and facsimile
(5) Instrument (3 items)	(5)-1. Pianos excluding electric pianos, (5)-2. Electric pianos, and (5)-3. Miscellaneous instruments
(6) Furniture (17 items)	(6)-1. Dressers (Height less than 1 m), (6)-2. Dressers (Height 1 m to less than 1.5 m), (6)-3. Dressers (Height 1.5 m or above), (6)-4. Cupboard (Height less than 1 m), (6)-5. Cupboard (Height 1 m to less than 1.5 m), (6)-6. Cupboard (Height 1.5 m or above), (6)-7. Bookshelf (Height less than 1 m), (6)-8. Bookshelf (Height 1 m to less than 1.5 m), (6)-9. Bookshelf (Height 1.5 m or above), (6)-10. Miscellaneous Furniture (Height less than 1 m), (6)-11. Miscellaneous Furniture (Height 1 m to less than 1.5 m), (6)-12. Miscellaneous Furniture (Height 1.5 m or above), (6)-13. Beds, (6)-14. Table sets, (6)-15. Reception sets, (6)-16. Study desks and learning desks, and (6)-17. Study chairs and learning chairs
(7) Transportation equipment (6 items)	(7)-1. Cars with a cubic capacity of 660 cc or below, (7)-2. Cars with a cubic capacity of above 660 cc, (7)-3. Motorbikes with a cubic capacity of 50 cc or below, (7)-4. Motorbikes with a cubic capacity of above 50 cc, (7)-5. Bicycles, and (7)-6. Miscellaneous transportation equipment
(8) Interior accessories (7 items)	(8)-1. Wall clocks and clocks, (8)-2. Lighting equipment, (8)-3. Carpets, (8)-4. Curtains, (8)-5. Cushions, (8)-6.Futons, and (8)-7. Bed linens
(9) Kitchen/ household goods (10 items)	(9)-1. Bowls and dishes, (9)-2.Chopsticks, spoons, forks, and knives, (9)-3.Glasses and teapots, (9)-4. Kitchen knives and kitchen scissors, (9)-5. Rice paddies, washtubs, bamboos, bowls, bats, and chopping boards, (9)-6. Kitchen scales, measuring cups, measuring spoons, bottle openers, and trays, (9)-7. Hammers, drivers, saws, and sewing equipment, (9)-8. Shovels, watering hoppers, and hoppers, (9)-9. Light bulbs, and (9)-10. Towels
(10) Clothes (2 items)*	(10)-1. Clothes less than 10,000JPY and (10)-2. Clothes more than 10,000JPY

(11) Bags/shoes/umbrella (6 items)*	(11)-1. Second bags and tote bags, (11)-2. Suitcases and carry bags, (11)-3. Handbags and miscellaneous bags, (11)-4. Footwear less than 10,000JPY, (11)-5. Footwear more than 10,000JPY and (11)-6. Umbrella
(12) Education/entertainment goods (11 items)	(12)-1. Stationeries, (12)-2. Sporting goods, (12)-3. Children's toys, (12)-4. Music CDs, video DVDs, and Blu-ray, (12)-5. Books, (12)-6. Golf equipment, (12)-7. Ski and snowboard equipment, (12)-8. Outdoor equipment, (12)-9. Miscellaneous exercise equipment, (12)-10. Video games, and (12)-11. Video game software
(13) Hairdressing/beauty equipment (2 items)	(13)-1. Hair dryer and electric shaver and (13)-2. Miscellaneous hairdressing/beauty equipment
(14) Miscellaneous goods (2 items)	(14)-1. Pictures and Antiques and (14)-2. Jewel, noble metal, and watches

*Note: 1JPY=0.0088USD (11/8/2017)

Table A.2 Results of demographic characteristics

Sex	Male	240	Type of housing (Construction type)	Detached housing	126
	Female	175		(Wooden)	106
Age group	20 years to 24 years	8		(Non-wooden)	18
	25 years to 29 years	28		(Others)	2
	30 years to 34 years	29		Complex housing	284
	35 years to 39 years	59		(Wooden)	36
	40 years to 44 years	61		(Non-wooden)	236
	45 years to 49 years	69		(Others)	12
	50 years to 54 years	57		Miscellaneous	5
	55 years to 59 years	44		(Wooden)	1
	60 years or above	60		(Non-wooden)	3
Number in household including respondents	1	114		(Others)	1
	2	86	Total floor area	Below 29 m^2	34
	3	100		30 $m^2$to 49 m^2	46
	4	84		50 $m^2$to 59 m^2	35
	5	23		60 $m^2$to 69 m^2	43
	6	5		70 $m^2$to 79 m^2	49
	7	3		80 $m^2$to 99 m^2	55
Annual income of household*	Below 3 million JPY	64		100 m^2 or above	55
	3 million JPY to 4.99 million JPY	80		Unknown	98
	5 million JPY to 6.99 million JPY	80	Construction period	Before 1962	14
	7 million JPY to 9.99 million JPY	64		1963to 1971	17
	10 million JPY to 14.99 million JPY	53		1972to 1980	32
	15 million JPY to 19.99 million JPY	10		1981to 1989	55
	20 million JPY or above	4		1990 to 2001	84
	Unknown/I do not want to answer	60		Since 2002	158
Storeys of detached housing	One storey	2		Unknown	55
	Two storeys or above	124			
Storeys of complex housing	One storey	53			
	Two storeys or above	231			

*Note: 1JPY=0.0088USD (11/8/2017)

Table A.3 Average micro material stock derived from consumer goods in a housing unit

Type of housing	Total floor area [m^2]	Total	(1) Household equipment	(2) Home appliances	(3) Air conditioning equipment	(4) Audio/visual equipment	(5) Instruments	(6) Furniture	(7) Transportation equipment
Detached housing	Below 29	2,984	66	179	112	5	0	59	1,536
	30to 49	5,713	69	178	121	4	46	1,181	1,446
	50to 59	3,137	44	145	168	3	19	625	1,559
	60to 69	4,643	50	186	115	3	89	256	1,463
	70to 79	6,295	72	228	177	4	58	1,042	1,369
	80to 99	8,082	69	221	196	4	46	784	1,616
	100 or above	10,017	78	194	207	4	100	1,301	1,430
	Average	5,839	64	190	156	4	51	750	1,488
Complex housing	Below 29	2,914	39	115	48	1	2	197	48
	30to 49	3,245	50	133	72	2	3	416	453
	50to 59	4,864	57	166	100	2	19	425	572
	60to 69	6,192	54	181	122	3	36	786	772
	70to 79	7,686	64	207	121	3	41	1,221	1,116
	80to 99	9,010	53	176	146	3	79	1,104	1,106
	100 or above	6,078	73	160	146	3	89	1,318	1,437
	Average	5,713	55	163	108	3	38	781	786

Unit: kg

Table A.3 Average micro material stock derived from consumer goods in a housing unit(Continued)

Type of housing	Total floor area [m^2]	(8) Interior accessories	(9) Kitchen/household goods	(10) Clothes	(11) Bags/shoes/umbrella	(12) Education/entertainment goods	(13) Hairdressing/beauty equipment	(14) Miscellaneous goods
Detached housing	Below 29	88	353	50	483	52	8.62E-10	0
	30to 49	185	239	86	599	1,043	3.88E-09	516
	50to 59	48	95	25	283	123	0	0
	60to 69	202	261	129	757	502	3.74E-09	630
	70to 79	287	463	353	750	611	5.31E-09	880
	80to 99	280	384	321	1,137	1,796	1.97E-08	1,228
	100 or above	484	969	332	1,873	933	7.30E-09	2,113
	Average	225	395	185	840	723	5.83E-09	767
Complex housing	Below 29	68	142	893	480	411	3.01E-09	471
	30to 49	90	210	124	460	567	5.19E-09	664
	50to 59	125	293	343	495	1,170	6.20E-09	1,097
	60to 69	280	332	334	1,045	1,079	8.41E-09	1,169
	70to 79	344	411	402	1,196	1,191	1.20E-08	1,368
	80to 99	326	596	835	2,184	1,081	7.70E-09	1,322
	100 or above	339	771	148	828	249	5.86E-09	518
	Average	224	394	440	955	821	6.91E-09	944

Unit: kg