Characterization and Management of Disaster Waste: Case of Gorkha Earthquake Nepal

Raju Poudel

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Chapter 1

Introduction

1.1 Background

Disasters are the non-routine event which occurs suddenly in natural form like earthquake, fire, flood, tsunami, hurricane, and volcano; or that occur in prolonged onset such as civil conflict or drought; resulting in varying degrees and types of physical and social impacts [1]. Among many disasters, climate-related disasters have increased in terms of frequency and intensity over the past decades [2]. The impact of these disasters occurred either naturally or by human activities, not only has human dimensions, but also the environmental one [3]. The major human impacts are casualties including people being killed, injured and misplaced while the destruction of infrastructures, building collapse, property damage and crop damage are some major environmental impacts including physiological impacts [4].

These disasters can produce huge quantities of solid and liquid waste that threaten public health, hinder reconstruction and impact the environment [5]. Disaster waste is a solid and liquid waste which comes from a disaster, including debris (e.g., concrete, rebar, roof), vegetation (e.g., trees, limbs), inundated motor vehicles, and hazardous chemicals [6]. In other words, disaster waste is an abnormal generation of waste in the form of solid or liquid form as a result of disaster or conflict [5]. Thus, the local and regional waste management systems are not capable of coping the quantities and composition of waste produced, resulting in the problem of collection and disposal. Also, disaster waste is the mix of different type of waste making the management complex with potential presence of hazardous materials on it which might create severe health issues.

Disasters events are generally devastating that result in large physical damage which can create enormous amounts of demolition waste from the damaged buildings and infrastructures [7]. Construction and demolition waste are the major component in disaster waste in most of the cases [1]. The amount of disaster waste varies according to the type of disaster; its composition and nature. For example, the debris generated from the tsunamis is often more complicated to handle than the debris generated by other disasters [8]. The recent disaster events and the amount of disaster waste generated by those disasters are presented in Table 1-1. Immediately after the disasters, it adds a challenge and complexity of extreme large volume debris which pressurizes the shocked community [9]. Building waste in disaster waste was much voluminous and appropriate treatment and management of these bulk amounts of materials generated after the big disasters has become an enormous task for the governments in the affected area [10]. Immediate collection of these types of waste is prime work after the disaster event for various reasons. The generated debris primarily blocks the roads which hinder the rescue mission to respond the victims and prevents the people going back to their home.

Table 1-1: Past disaster events and disaster waste generated

Year	Event	Debris Volume	Data Source
2011	Tohoku Earthquake and Tsunami, Japan	Over 23 mil. tons	[8]
2011	Christchurch Earthquake, New Zealand	8 mil. tons	[11]
2010	Haiti Earthquake	23-60 mil. tons	[12]
2008	Sichuan Earthquake, China	20 mil. tons	[13]
2005	Hurricane Katrina, USA	76 mil. cum	[14]
2004	Indian Ocean Tsunami	10 mil. Cum (Indonesia alone)	[15]
2004	Hurricane Charley, USA	18 mil. Cy	[16]
1999	Marmara Earthquake, Turkey	13 mil. tons	[17]
1995	Great Hanshin-Awaji Earthquake, Japan	20 mil. tons	[18]

Another probable consequence, if the waste is not removed timely, there might be a chance of spreading of different types pathogens as a result of piles of waste which provides the favorable environment to these disease-causing pathogens and insects. The exposure of waste for extended period is risky for the public as well as environmental health [3]. For example, poor sanitation conditions of the camps of disaster victims or support troops resulted in outbreak of cholera in Haiti after the 2010 Haiti earthquake [19]. As the debris are generated at once after the disasters for which would be very large amount compared to the daily solid waste generated in the area. For instance, the waste generated in the town of Ishinomaki after the Great East Japan Earthquake was 6.16 million tons which was equivalent to the normal solid waste that would usually have been generated in 103 years [8]. The waste managers are unable to handle this amount of waste generated suddenly. These problems are more severe in developing countries as they are not prepared to deal with such large amount of waste, and daily waste collection and handling are not sufficient to address the large debris quantities. Proper strategies and plans must be prepared in advance to handle the disaster event and its consequences effectively. These strategies and plans might vary according to the varying geographical conditions which remain different for different countries and handling and management of waste by each country is not identical.

Nepal is one of the most disaster prone countries in the world and as the active fault line pass through the country, the country is highly susceptible to the effects of earthquake among all disasters [20]. Nepal was hit by the powerful Gorkha earthquake of magnitude 7.8 on April 25, 2015 with its epicenter at Barpak, Gorkha, 80 km northwest of Kathmandu Valley. On May 12, 2015, a 7.3 magnitude aftershock caused large devastation in fourteen districts of Nepal. According to the Government of Nepal, a total of 8,856 people lost their lives and 22,309 people were injured. More than 600,000 buildings collapsed completely, while more than 280,000 buildings were partially damaged. In the Kathmandu Valley, which contains the capital of Nepal and consists of 3 major districts (Kathmandu, Lalitpur, and Bhaktapur), 73,317 buildings were fully destroyed and 67,871 buildings were partially damaged [21]. This devastating earthquake impacted one-third of the population (8 million people) [22] and resulted in collapse of buildings fully or partially with estimated losses of US$ 7 billion [23]. Large amount of disaster debris was generated by the earthquake which added challenges to Nepal, which still struggles with daily management of waste [24]. As a result of earthquake, the mud mortar-jointed masonry buildings experienced maximum damage which constituted more than 85% of the total damaged buildings.

Disaster waste in Kathmandu Valley constituted useful building materials which could have been recovered up to 80-90% [25]. However, the building materials used in older buildings might not confirm the new building standards which limit the recovery of materials from debris. The reconstruction works required large quantities of building materials. As for example bricks, an important building material; if recovered from the debris of damaged buildings, could save large amounts of coal and soil as source of energy and raw materials, respectively[26].

Disaster waste quantification and classification is the prime step for the planning process for appropriate collection, sorting and treatment systems. These data are the base for formulating appropriate strategies in cost-reduction in debris removal, treatment and utilization of debris. Disaster waste estimation can be a challenging work of which the composition and volume of the waste depends on both the built environment and severity of the disaster. However, the estimates of disaster waste generally do not specify the composition of the generated disaster waste [27]. Two basic methods can be applied for the debris estimates after the disaster: material stock estimation and post-disaster field estimation. In material stock estimation, net building materials used during the construction of the building that correspond to the quantity of generated waste. This method can be used to estimate waste after and prior to the disaster event, which are helpful in planning process. However, in post-disaster field estimation, quantification is done after the disaster where loss of building materials occurs if important reusable and recyclable materials are sorted and removed before the authorized estimation is done. Developed countries have developed the guidelines on disaster waste management based on previous experience. The guidelines for estimating debris quantities made use of tapes, GPS, aerial and satellite photographs before and after disaster and computer models [28]. Also the estimation method made use of hazard maps, GIS data, fragility curves on standard damage level for buildings and per unit generation of debris with pre available data based on past disasters [18]. Other estimation methods were based on the satellite images before and after the disaster; GIS based building registration and European Microseismic scale (EMS-98) for the quick assessments [29]. There are no well-developed guidelines and legal frameworks for estimating and managing disaster waste in developing countries.

Debris generated suddenly after the disaster are huge in quantity which overwhelms the existing solid waste management facilities affecting the emergency and recovery activities [30]. Proper treatment and management of these large quantities of debris waste becomes a difficult task for the government that requires costly and complex operations requiring months or years to clear the debris [31]. Debris removal need to be done in two phases i.e., initial clearence for rescue opreations and derbis removal for recovery.

The debris generated in Kathmandu Valley, Nepal after the Gorkha earthquake was expected to be very large for which the government planned to deposit on the old limestone quarry site of Himal Cement Factory, approximately 7 km south of the core city area in Chobhar [32]. After 2 years from the Gorkha earthquake, no debris was deposited in Chobhar site despite of the government plan. Debris generated in Kathmandu core city area were managed within the city on river banks, side of ring road (open dumping), land development projects and by reusing the useful building materials. There were no or very less information about the disposal methods and quantities of disaster debris generated in the core city [33].

Kumamoto area of Japan was struck by the strong earthquake of magnitude 6.5 on April 14, 2016 which was followed by next quake of magnitude 7.3 on April 16. This disaster event led to the death of 244 people and injured more than 2,700 people. The earthquake also damaged more than 170,000 houses and other buildings (8,248 completely destroyed, 30,475 partially destroyed and 132,974 partly destroyed). The damages of the earthquake resulted in the estimated direct economic losses of USD 22.4-43.0 billion (JPY 2.4–4.6 trillion yen) [34]. The amount of disaster waste in Kumamoto prefecture was estimated to be 3.16 million tons. The disposal of disaster waste in Kumamoto, it is primarily important to treat these wastes however the facilities like incinerator plants, night soil treatment plants were severely damaged by the earthquake. These facilities took some time to repair before treating the debris waste.

For the management of disaster waste effectively, the debris were roughly classified at its origin and sent to the primary temporary waste storage site. The debris materials are taken to the secondary sites if there is no enough classification or the primary storage sites have limited capacity. Immediately after the earthquake, 54 primary storage sites were set up in Kumamoto that eventually reached to 80. The disaster waste was processed for reuse, recycling, incineration and landfill. For the reduction and recycling of disaster waste, the waste was processed at the classification stage by crushing and separation machines with the target recycling rate of over 70%. The cooperative networks among different organizations in Japan are important in dealing with the large amount of disaster waste. The skills and experiences of the organizations are useful in in dealing to the disaster waste in future and support the organizations of affected area [35].

This thesis mostly describes about the disaster of Gorkha earthquake 2015 Nepal, consequences of disaster resulting in the generation of disaster waste and its management in Kathmandu Nepal. However, the case of disaster event of Kumamoto earthquake 2016 Japan and the management of disaster waste in Kumamoto is a part of this thesis. It was included in the thesis as the type of disaster occurred in both Nepal and Japan were of same type i.e. earthquake and of almost similar magnitude that occurred in consecutive years (or within a year). The other reasons are to learn the disaster waste management aspect for the disaster waste generated by Kumamoto earthquake; to make a comparative study between developed country (Japan) and the developing country (Nepal) in disaster waste management; and the co-incidence of working with disaster waste management of Nepal (home country of the researcher) and similar event case was found in the country Japan where the researcher was studying.

1.2 The aim of the study

The main objective of this thesis is (1) to quantify the debris generated by the earthquake in Kathmandu Valley Nepal for different types of buildings, (2) to investigate the debris waste generation and management practice after the Gorkha earthquake in Kathmandu Valley, Nepal and (3) to elaborate the disaster waste management status of Kumamoto Prefecture after the Kumamoto earthquake. The specific objectives were as follows:

(i) To develop a quantification procedure of the building debris from the earthquake damage buildings in Kathmandu Valley which can be used for determining the total and individual building debris aftermath and pre-disaster.

(ii) To investigate building debris management practice after the earthquake relief, recovery, rehabilitation and reconstruction phases, as well as actual methods of building waste disposal in Kathmandu Valley Nepal, two years after the earthquake. Additionally, to estimate the amount of debris deposited in the core city area of Kathmandu Valley (Kathmandu Metropolitan City and Lalitpur Sub-Metropolitan City).

(iii) To explain the damages and disaster waste generated by the Kumamoto earthquake and describe the waste management system applied. Further elaborate about the recycling facilities involved for debris treatment and cooperative networks for supporting in disaster waste management.

1.3 Structure of the thesis

The structure of the thesis is presented in Figure 1-1 which contains five main chapters as briefly described as follows:

Chapter 1 outlines the background of the disaster waste generation and management studies and determines the aim and scope of the study.

Chapter 2 presents the establishment of unit generation rates of building debris for different types of buildings in Kathmandu Valley Nepal after the Gorkha Earthquake for quantifying the disaster waste generation

Chapter 3 presents the status of disaster waste management and its disposal in Kathmandu Nepal during field studies after the Gorkha earthquake.

Chapter 4 presents the review study on earthquake waste management and experience of after the 2016 Kumamoto Earthquake

Chapter 5 draws the conclusions and recommends for the future research

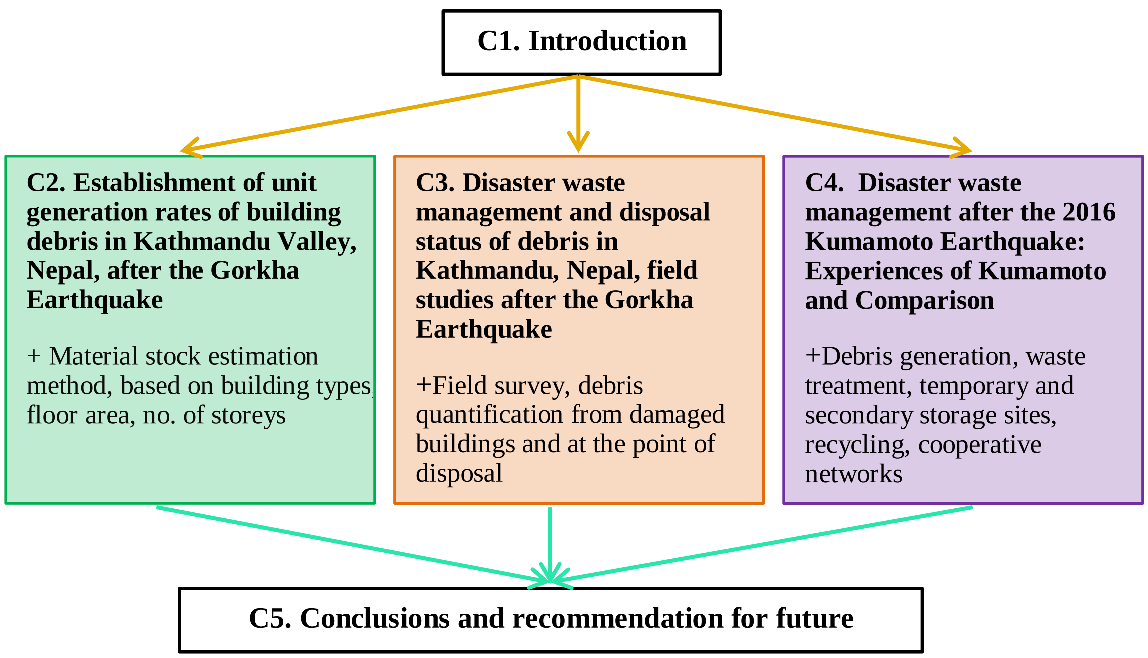

Figure 1-1: Structure of the thesis

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Chapter 2

Establishment of Unit Generation Rates of Building Debris in Kathmandu Valley, Nepal, after the Gorkha Earthquake

2.1 Introduction

2.1.1 Gorkha earthquake and its impact

On April 25, 2015, a 7.8 magnitude earthquake occurred in Nepal, with its epicenter at Barpak, Gorkha, 80 km northwest of Kathmandu Valley. On May 12, 2015, a 7.3 magnitude aftershock caused large devastation in fourteen districts of Nepal. According to the Government of Nepal, a total of 8,856 people lost their lives and 22,309 people were injured. More than 600,000 buildings collapsed completely, while more than 280,000 buildings were partially damaged. In the Kathmandu Valley, which contains the capital of Nepal and consists of 3 major districts (Kathmandu, Lalitpur, and Bhaktapur), 73,317 buildings were fully destroyed and 67,871 buildings were partially damaged [1].

The large amount of building waste generated by strong earthquakes contains about 70-90% demolition waste composed of concrete, bricks, and fines, all of which can be reclaimed and recycled [2]. Disaster waste has therefore drawn the attention of civil engineers and local government officials, who seek statistics on the amounts and types of waste generated so that they can develop reclamation plans [3].

In Kathmandu Valley, it is estimated that 80 to 90% of disaster waste could be recovered [4]. However, because of various difficulties in separating the various materials, not everything is recovered. After separation, many of the materials would have to be remade to conform to new building standards. As a result, only a few materials, such as bricks, wood/timber, and metals, are ultimately recovered for reuse or send for recycling. While bricks are produced in Kathmandu Valley, building materials such as aggregates and sand are usually transported from 14 nearby districts at distances of 25 to 40 km over hilly roads [5]. An estimated 1.12 billion bricks would be required for the reconstruction of buildings across Nepal, which would require large amounts of coal and soil as sources of energy and raw materials, respectively [6]. If instead the raw materials were recovered from the disaster waste, rebuilding would be completed more quickly and be less expensive.

Disaster waste quantification and classification is the first step in planning appropriate collection, sorting, and treatment systems. Without such data, the concerned agencies will not be able to formulate appropriate cost-reducing strategies for debris removal, treatment, and utilization. Post-earthquake reconstruction activities would benefit from systematic access to materials recycled from the disaster waste. The purpose of the study is to develop a quantification procedure of building debris from earthquake damaged buildings in Kathmandu Valley which can be used for determining the total and individual building debris aftermath and pre-disaster.

2.1.2 Disaster waste estimation

Estimating earthquake debris quantities can be challenging, however, since the composition and volume of waste depends on both the built environment and the disaster severity. While there are guidelines for estimating disaster waste, they are limited when attempting to rapidly determine quantities that take into account the extent of damage to buildings. Furthermore, estimates generally do not specify the composition of generated disaster waste [7]. Management of the large volume of debris waste after the large earthquake is an enormous task for the government and local bodies.

Debris estimation can be done using one of two basic methods: material stock estimation and post-disaster field estimation.

2.1.2.1 Material stock estimation

For material stock estimation, the net amounts of building materials used during construction are computed, and this value assumed to correspond to the quantity of generated waste. This method can be used to calculate the amounts of materials both in and above the foundation. Debris generation can be estimated prior to a disaster event, making it particularly useful for planning purposes.

2.1.2.2 Post-disaster field estimation

Post-disaster field estimation, on the other hand, involves quantifying the amount of building material collected after a disaster. In this method, some loss of building materials can occur if important reusable and recyclable materials are sorted and removed before an authoritative estimate is developed. Conversely, the collected debris may contain large amounts of household goods that are not part of the structures. Such estimates do not include building foundations, since the foundations are not typically removed for disposal.

Thus, "material stock estimation" of debris might give almost constant debris quantity whereas the "post-disaster field estimation" might fluctuate depending upon different factors.

The estimation of the debris waste is usually made after the big disaster events and the amount of waste generated is based on the assumption rather than the exact quantification. Developed countries like the

United States and Japan have disaster waste management guidelines that they developed based on past experiences. The Federal Emergency Management Agency (FEMA) in the US has a field guide for estimating debris quantities with the use of tapes, GPS, aerial and satellite photographs from before and after the disaster, and computer models [8].

Japan uses methods based on hazard maps with GIS data, fragility curves on standard damage levels for buildings, and per unit generation of debris with pre-available data based on past disasters [9]. Another estimation method developed in Japan makes use of satellite images (QuickBird) before and after a disaster, GIS-based building registration, and the European Macroseismic Scale (EMS-98) for quick assessment and quantification. This method was applied to the 2003 earthquake in Bam, Iran [10].

Developing countries, however, do not have well-developed guidelines and legal frameworks for estimating and managing disaster waste. For example, building debris was estimated by the Department of Urban Planning and Housing in Banda Aceh, Indonesia, based on the estimated number of housing units that needed to be built after the tsunami on December 26, 2004 [11].

2.1.3 Building types in Kathmandu Valley

There are many types of buildings in Kathmandu Valley, including historical, monumental, governmental, and commercial buildings; traditional compounds with a courtyard; and detached houses. These buildings have historically been constructed as a necessity of life in accordance with the available material, economic power and rules of thumb, in the Kathmandu Valley.

According to National Population and Housing Census 2011 of Nepal [12] buildings were classified by the type of foundation of house, outer wall and roof of the house. Cement bounded brick/ stone and cement concrete with pillar buildings are highly popular in urban area in most of the Terai (flat land in south part of Nepal) region, Kathmandu Valley and some district headquarter of mountainous region[13]. In Kathmandu Valley, 35% of the houses are constructed with RC roofs and load-bearing walls, while 37% have RC roof and frame structures. Another 20.04% have corrugated galvanized iron (CGI) roofs, while 4.02% have tile/slate roofs. The remaining buildings have thatch/straw or other roof types. The buildings with CGI, tile/slate, and thatch/straw roofs all have load-bearing structures[12].

According to the building inventory, the major structural types of buildings are classified as follows [14]:

- Reinforced concrete frame with/without brick masonry (RC): rapidly increasing numbers of buildings at urban core and fringe areas.
- Brick with cement (BC): most common type and more or less half of the buildings in the area.
- Adobe (AD): popular in rural areas.

- Other Buildings.

Figure 2-1 provides a visual representation of the buildings in Kathmandu Valley classified by roof and structural system.

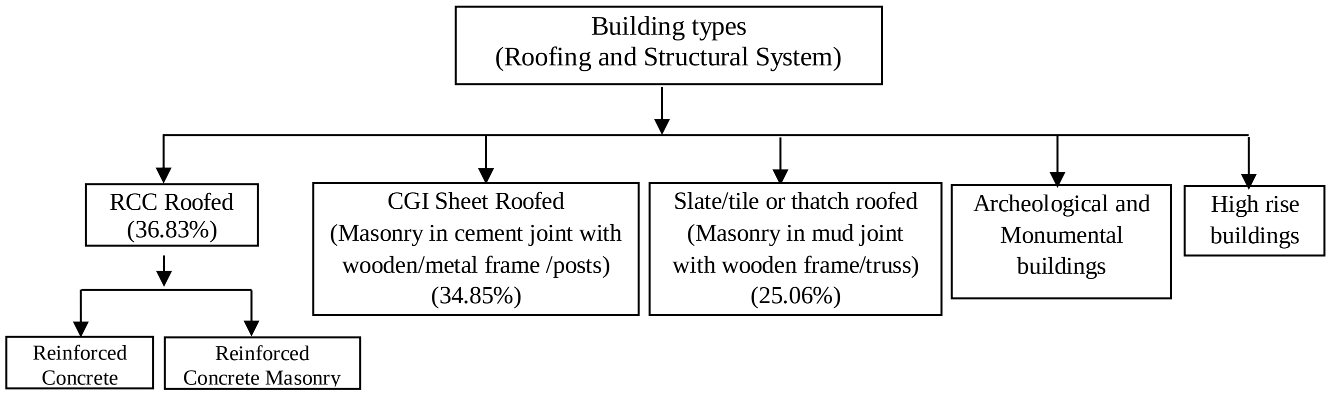


Figure 2-1: Types of buildings according to roof and structural system (values are for foundation type only)

In RC framed building, the load of the entire building is transferred from slab to the beams and columns and finally to the footing. Walls in these types of buildings are to separate the room or for external covering. In RC masonry type buildings, the load of entire building is transferred from the slab to the walls of the building and finally to the footing. The thickness of the wall is increased in order to withstand the overall load in RC masonry type buildings. Similarly, the load of roofing and entire load is taken by the thick load bearing wall or wooden beams and column in the inner part of the buildings with CGI sheet roof or tile/slate roofed house. Buildings can be further classified in terms of their use. According to this classification, buildings are either public buildings such as school, hospitals, government buildings, community halls etc. or private buildings for the residential use. The rooms, staircases, and hallways are larger in public buildings to provide service for large numbers of people, while residential buildings are typically designed for a small number of people in any given area.

2.2 Methods

The method of the study was based on the case study with the assumption that the quantity of disaster debris was equivalent to the material quantities used during construction of the building.

2.2.1 Selection of buildings

The details of type of the buildings, no. of stories, features of the buildings, utility of the buildings, number of buildings under consideration, source of detail drawings and quantity estimate and current building status for the buildings under study are given in Table 2-1.

Table 2-1: Building characteristics under study

S.N.	Building Type and stories	Symbol	Features	Building Utility Type	Source of Detail Drawings	Source of Quantity Estimate	Building Status
A. Buildings actually existed and resources obtained from Office							
1	Reinforced Concrete; 2 storied	RC 2S	RCC roofed and RCC framed structure with cement mortar jointed masonry	Public	Obtained from Vyas Municipality	Obtained from Vyas Municipality	Actual
2	Reinforced Concrete; 1 storied	RC 1S	RCC roofed and RCC framed structure with cement mortar jointed masonry	Public	Obtained from Vyas Municipality	Obtained from Vyas Municipality	Actual
3	Masonry-CGI sheet roofed (C/S joint); 1 storied	M-C	CGI sheet roofed and load bearing wall structure with cement mortar jointed masonry	Public	Obtained from Vyas Municipality	Obtained from Vyas Municipality	Actual
4	Reinforced Concrete; 2 storied	RC1 2S	RCC roofed and RCC framed structure with cement mortar jointed masonry	Residential	Obtained from Vyas Municipality	Our Estimation	Actual
5	Reinforced Concrete; 2 storied	RC2 2S	RCC roofed and RCC framed structure with cement mortar jointed masonry	Residential	Obtained from Vyas Municipality	Our Estimation	Actual
6	Masonry-CGI sheet roofed (C/S joint); 1 storied	M-C1	CGI sheet roofed and load bearing wall structure with cement mortar jointed masonry	Residential	Obtained from Vyas Municipality	Our Estimation	Actual
7	Masonry-CGI sheet roofed (C/S joint); 1 storied	M-C2	CGI sheet roofed and load bearing wall structure with cement mortar jointed masonry	Residential	Obtained from Vyas Municipality	Our Estimation	Actual
B. Buildings derived from existed one and modified calculation from existed resources							
8	Reinforced Concrete and Masonry ; 2 storied	RC-M 2S	RCC roofed and load bearing wall structure with cement mortar jointed masonry	Public	Used same drawing as of S.N.1	Our Estimation	For calculation purpose
9	Reinforced Concrete and Masonry ; 1 storied	RC-M 1S	RCC roofed and load bearing wall structure with cement mortar jointed masonry	Public	Used same drawing as of S.N. 2	Our Estimation	For calculation purpose
10	Reinforced Concrete and Masonry ; 1 storied	RC-M1 2S	RCC roofed and load bearing wall structure with cement mortar jointed masonry	Residential	Used same drawing as of S.N. 4	Our Estimation	For calculation purpose
11	Reinforced Concrete and Masonry ; 2 storied	RC-M2 2S	RCC roofed and load bearing wall structure with cement mortar jointed masonry	Residential	Used same drawing as of S.N. 5	Our Estimation	For calculation purpose
C. Buildings of old types (Buildings exists but no resources for such buildings are available) and calculated based on assumption							
12	Masonry-Tile roofed(mud joint); 2 storied	M-T(M) 2S	Tile roofed and load bearing wall structure with mud jointed masonry	Residential	Drawing prepared by us	Our Estimation	For calculation purpose
13	Masonry-CGI sheet roofed(mud joint); 2 storied	M-C(M) 2S	CGI sheet roofed and load bearing wall structure with mud jointed masonry	Residential	Drawing prepared by us	Our Estimation	For calculation purpose

About 96% of the building types in Kathmandu Valley are represented in this study, which excludes archeological, monumental, and high-rise buildings. Cement bonded masonry with CGI sheet roof (M-C), reinforced concrete (RC) building and reinforced concrete and masonry (RC-M) building are identical and popular in the urban area in most of the Terai (flat land in south part of Nepal) region, Kathmandu Valley and some district headquarters of mountainous region [13]. Buildings constructed in the Damauli area of Vyas Municipality; headquarter of hilly district Tanahun, were chosen for the current analysis as representative of the buildings in the hilly region for Kathmandu Valley. Detail drawings and detail quantity estimates of the buildings under study were obtained and used to make the material stock estimations as described in Table 2-1.

2.2.2 Method of estimation

The quantities of building materials were calculated with the help of detail drawings and detail quantity estimate sheets available from the office and prepared by the authors based on detail drawings. Detail drawings and detail quantity estimates for public buildings RC 2S, RC 1S and M-C were prepared by Sub-Engineers and Engineer of Vyas Municipality Office, Nepal and detail drawings of residential buildings RC1 2S, RC2 2S, M-C1 and M-C2 were among approved buildings for construction in Vyas Municipality, Tanahun (rows 1 through 7 in Table 2-1). Detail drawings and detail quantity estimates of the buildings available in Vyas Municipality were obtained through personal communication with Sub-Engineers Mr. Shree Krishna Bagale and Mr. Binod Gautam with the approval of Acting Executive Officer Mr. Kumar Kanchan GC, of Vyas Municipality, Nepal on 18th February 2016. Accordingly, the detail quantity estimates of buildings RC1 2S, RC2 2S, M-C1 & M-C2 were prepared by the authors with the help of detail drawings obtained from the office. It was prepared by measuring the individual parts of the building like wall, floors, roof slabs, beam, pillar, door/windows frame from drawings in length, breadth, height and calculating the volumetric quantity of building materials used on each part during construction with measurements provided in detail drawings. For the ease of calculation, firstly the whole volume of building part like wall is calculated and deductions for the volume of windows, doors were done for exact quantity of masonry in walls. Calculation for quantity of building materials was started from foundation works and gradually to the upper levels. Building materials or item works done in each parts of a building were quantified and summed up under a similar head of building material for total quantity of each building materials. Quantification of works or items in building like soil excavation, masonry, concrete works, door/window frames were done in volume; plasters, punning, paint works, door/window shutter, CGI roofing are measured in area (m^2) and materials like iron bars were measured in length, diameter size and finally in weight from standard weight for unit length of different sized iron bars. Steel reinforcement was taken as a volume percentage of the reinforced concrete, at 1 to 2% for beams, 1 to 5% for columns, 0.5 to 0.8% for foundations, and 0.7 to 1% for slabs. Similar process was followed for the estimation of different types of buildings for calculating the quantities of different materials in the building.

Also, detail quantity estimation of the RC masonry buildings RC-M 2S, RC-M 1S, RC-M1 2S and RC-M2 2S (rows 8 through 11 in Table 2-1) were done by the authors with the help of drawings of buildings RC 2S, RC 1S, RC1 2S & RC2 2S respectively by replacing the quantities of footings, beams and columns of RC buildings by brick masonry and increasing the thickness of the walls by 1.5 to 2 times as that of RC structure. As tile roofed-mud bonded masonry structure [M-T (M) 2S] and CGI sheet roofed-mud bonded masonry structure [M-T(M) 2S] (rows 12 through 13 in Table 2-1) are old types of residential buildings, detail drawings of the buildings had not been registered in the Municipality. Thus, we assumed two-story typical building with a 30 ft x 24.5 ft floor area size and prepared detailed drawings for both buildings. Detailed quantity estimation of the buildings was prepared by authors with the help of above detail drawings. Thus, detail quantity estimates of thirteen different buildings were available for the purpose of analysis. Similar building materials used in various parts of building were summed up to get the exact quantity of each building materials and all measurements were then converted into weights using accepted material density or specific gravity values (weight per volume, area, or length, as appropriate). The unit weights of building materials used in this study are provided in Table 2-2.

Table 2-2: Unit weight of different materials

Building Materials	**Weight per Unit**	**Unit**	**Remarks**
Bricks Laying (Soling)	1920	kg m^{-3}	a
Stone Soling	2515	kg m^{-3}	b
Plain Cement Concrete (1:3:6)	2400	kg m^{-3}	c
Plain Cement Concrete (1:2:4)	2400	kg m^{-3}	c
Brick Masonry	1950	kg m^{-3}	d
Stone Masonry	2600	kg m^{-3}	e
Reinforcement (Steel bars)	7800	kg m^{-3}	c
Cement Sand Plaster	2000	kg m^{-3}	f
Cement Sand Punning	1506	kg m^{-3}	b
Saal Wood	950	kg m^{-3}	g
Sisam Wood	770	kg m^{-3}	g
Mud lying and plastering	2000	kg m^{-3}	h
CGI Sheet Roofing	5.32	kg m^{-2}	i
Tile Roofing	70	kg m^{-2}	j

Note:

a. *RF Café. Taking the value of Brick, common red 1920 kg m^{-3}.*[15]
b. *SI Metric, 2016. Taking values of Stone soling (Stone common, generic) and of Portland Cement for Cement Punning.[16]*
c. *Abdullah N., Suhelmiey M., Hamaz, S. S. H., 2015. Cement Concrete density: 2400 kg m^{-3}.* [17]
d. *Graziotti F., Tomassetti U., Penna A. and Magenes G., 2016.* [18]
e. *Scribd, 2016. Taking value 2600 kg m^{-3} of Granite stone from 2460-2800 kg m^{-3}.*[19]
f. *Tarmac, 2015. Taking 2000 kg m^{-3} for Compacted Set Screed.*[20]
g. *Wikipedia, 2016. Taking value 950 kg m^{-3} for Sal of 880-1050 kg m^{-3} and of Sisam wood.*[21]
h. *Ciancio D., Beckett C., 2013.Taking the value of rammed earth 2000 kg m^{-3}.*[22]
i. *Greenheck, 2004. For CGI Roofing: 26 gauge CGI sheet 0.906 lb ft^{-2} =0.906 lb ft^{-2} *4.88243 = 4.425 kg m^{-2}. 20% overlapping= 1.2*4.425 kg m^{-2}=5.32 kg m^{-2} (Calculated).* [23]
j. *Porteous, J and Kermani, A., 2008 Tile roofing load = 70 kg m^{-2}.[24]*

Volume and weight of total and individual quantities of building materials in a building were calculated. Similarly, volume and weight of total and individual quantities per unit area of building materials in a building were calculated. Also, the total and individual quantities of building materials were calculated for first floor and consecutive upper floors for different types of buildings. Drawing details of residential RC building are provided in Figure 2-2.

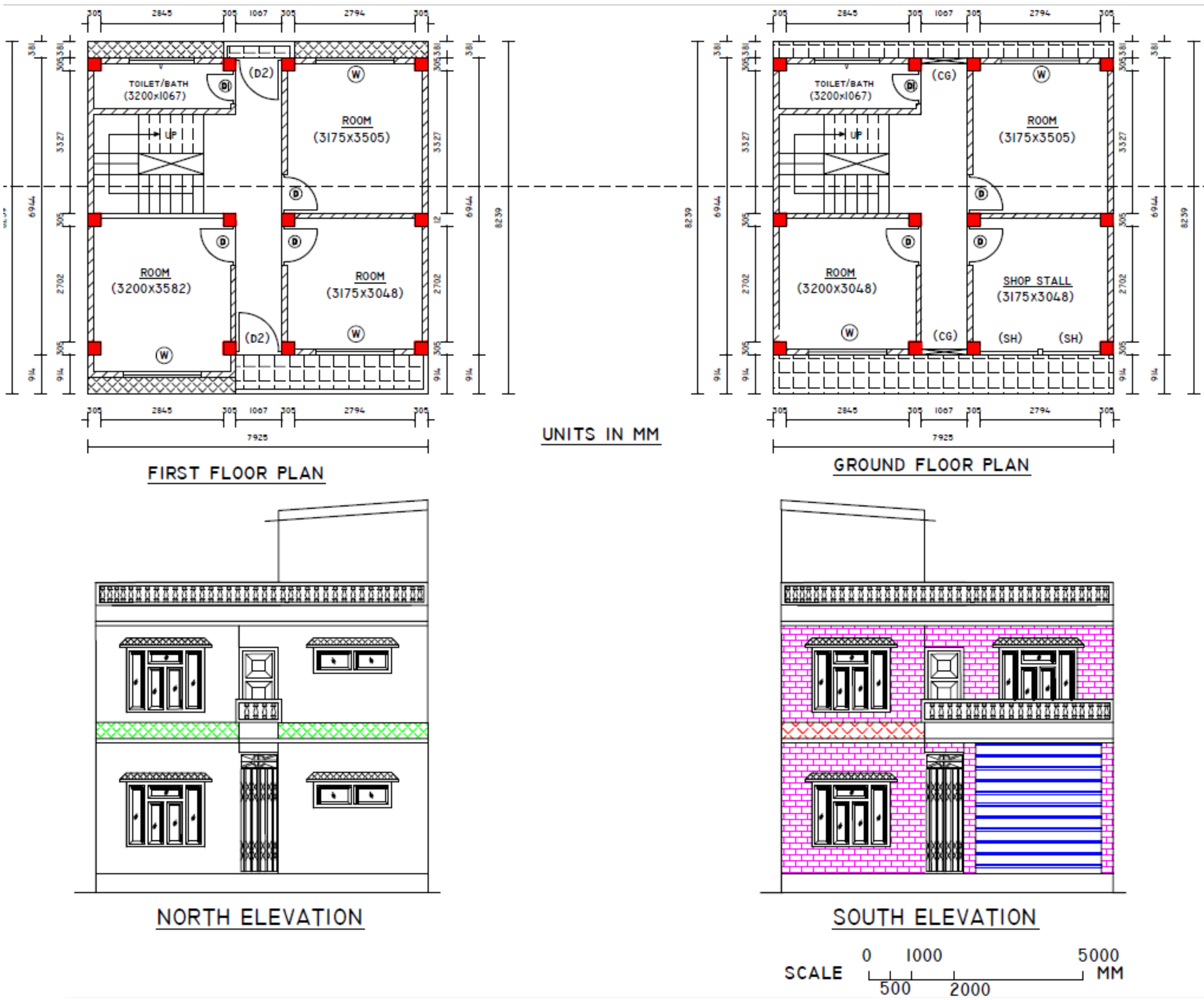


Figure 2-2: Residential reinforced concrete (Res. RC) building with floor area: 111.8m^2 (55.02m^2+56.86 m^2)

The total amount of debris expected from a given building can be calculated by the following equation.

$$\mathbf{Q} = \sum_c \sum_m \sum_k \boldsymbol{F}(\boldsymbol{c}) * \boldsymbol{M}(\boldsymbol{c}, \boldsymbol{m}, \boldsymbol{k}) \qquad \textbf{(1)}$$

where, **Q** is the total quantity of debris, **F** is floor area of the building (m^2), **M** is quantity of building material (kg m^{-2}), c is type of building, **m** is materials of building, **k** is types of particular material.

2.3 Results and discussions

2.3.1 Building waste generation rates for different buildings in Nepal

The overall unit generation rates estimated for each building are shown in Table 2-3, along with their component breakdown by material type. The major constituents were brick/stone, cement concrete, reinforcement bars, and wood/timber. The unit generation rates of brick/stone and concrete waste were similar to each other in the reinforced concrete (RC) structures, whereas the unit generation rate of masonry (bricks) was much higher than that of concrete in reinforced concrete masonry (RC-M) structures. Brick/stone was also the major constituent of the masonry with CGI or tile roofed [M-C, M-T(M) and M-C(M)] buildings.

The unit generation rates for residential buildings were higher than those for public buildings of the same type. The amount of building waste produced per unit areas of same structural type differ for public or residential purpose. Also the quantity of building waste generated per unit area of masonry CGI roofed, load bearing (M-C) in residential building is more than that of public building. The reason for residential buildings having more building waste per unit area is due to the smaller rooms in residential buildings causing a higher wall density per floor area than public buildings.

Table 2-3 shows that differences in the unit generation rates between the reinforced concrete (RC) and reinforced concrete masonry (RC-M) buildings were small for the same number of stories and building utility. The lowest unit generation rates occurred for the masonry with CGI roof (M-C) buildings for both public and residential building type. The order of the unit generation rates occurred from highest to lowest were reinforced concrete masonry (RC-M), reinforced concrete (RC), masonry with CGI roof (M-C), masonry-tile roofed (mud joint) [M-T(M)] and masonry-CGI sheet roofed(mud joint) [M-C(M)] respectively.

Table 2-3: Weight of materials (tons per m^2) of different conditions of buildings

Building Materials	1	2	3	4	5	6	7	8	9	10	11	12	13
	Pub. RC 2S	**Pub. RC-M 2S**	**Pub. RC 1S**	**Pub. RC-M 1S**	**Pub. M-C 1S**	**Res. RC1 2S**	**Res. RC-M1 2S**	**Res. RC2 2S**	**Res. RC-M2 2S**	**Res. M-C1 1S**	**Res. M-C2 1S**	**Res. M-T(M) 2S**	**Res. M-C(M) 2S**
Masonry (Bricks/Stone)	0.99	1.43	1.71	2.28	1.45	1.44	2.37	1.53	2.20	2.03	2.16	2.08	2.08
Concrete and Cement finish	0.98	0.59	1.28	0.74	0.41	1.47	0.83	1.30	0.70	0.49	0.59	0.00	0.00
Reinforcement bars	0.03	0.01	0.05	0.01	0.00	0.04	0.01	0.04	0.01	0.00	0.01	0.00	0.00
Wood/Timber	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.09	0.09
Others	0.00	0.00	0.00	0.00	0.03	0.01	0.01	0.01	0.01	0.03	0.03	0.33	0.29
Total	**2.01**	**2.04**	**3.05**	**3.04**	**1.90**	**2.97**	**3.23**	**2.88**	**2.93**	**2.57**	**2.80**	**2.49**	**2.45**

2S -- 2 Storied **1S** -- 1 Storied **RC---** Reinforced Concrete **RC-M----** Reinforced Concrete and Masonry **M-C----**Masonry and CGI roofed **M-T(M)---** Masonry and Tile roofed (joint in Mud mortar) **M-C(M)---** Masonry and CGI roofed (joint in Mud mortar)

The amount of building waste produced per unit areas of similar structural type differ with the number of stories. Unit generation rates for the first floor were more than those for the second floor in every building, while unit generation rates were higher for single-story buildings than for double-story buildings.

The unit generation rates, as volume and weight, for each building based on roof and structural type, its utility as public or residential purpose and number of floors (including and excluding of foundation) are summarized in Table 2-4. The values determined here for individual buildings can be used for calculating the potential building waste generation from the individual buildings as well as the total disaster waste from the damaged buildings. The material composition of the disaster waste can be calculated in a similar manner from the individual and group of buildings.

2.3.2 Total building waste generation rate and material composition

2.3.2.1 Comparison of total building waste in Nepal, Japan and China

The unit generation rates determined here for Nepal were then compared to unit generation rates published by other researchers for Japan and China (Figure 2-3). Material stock estimation was used for Nepal and Japan, while post-disaster field estimation was used in China. The comparison were made between reinforced concrete (RC), reinforced concrete masonry (RC-M) and masonry with CGI roof (M-C) for both public and residential buildings; and total building debris generated per unit in Nepal with reinforced concrete(RC) building in Japan and buildings of concrete frame structure (CFS), masonry frame structure (MFS) and masonry buildings (M) in China. The reinforced concrete (RC) buildings of Nepal can be structurally compared to reinforced concrete (RC) buildings in Japan and concrete frame structure (CFS) buildings in China. The reinforced concrete masonry (RC-M) and masonry with CGI roof (M-C) buildings in Nepal can be structurally compared, respectively, to the masonry frame structure (MFS) and masonry (M) buildings in China [3]. Unit generation rates of total and individual building materials for buildings were compared. Total and individual building material generated per unit area for different buildings are shown in Figure 2-3.

Unit generation rates in Nepal were found to be larger than those in China for all building types, which is likely due in part to the different estimation methods used. RC buildings in Japan had higher unit generation rates when compared to the public RC buildings of Nepal and China, but lower when compared to the residential buildings of Nepal. Bricks are used more extensively for building in Nepal, whereas a larger proportion of concrete is used in Japan and China. The amount of reinforcement used in Japan and China was also higher than that used in Nepal. For reinforced concrete (RC) structure or concrete frame structure (CFS), the amounts of concrete and brick/stone used for masonry were similar in Nepal, whereas more concrete than brick/stone was used for masonry in Japan and China. In China, more concrete was used for masonry frame structure (MFS) and masonry buildings (M) than reinforced concrete masonry (RC-M) and masonry with CGI roof (M-C) in Nepal.

Table 2-4: Quantity of building waste per unit area for different buildings

S.N.	Building Type and stories	Symbol	Building Utility Type	Building Waste per unit area (including foundation)		Building Waste per unit area (excluding foundation)	
				Quantity (ton m^{-2})	Volume (m^3 m^{-2})	Quantity (ton m^{-2})	Volume (m^3 m^{-2})
1	Reinforced Concrete; 2 storied	RC 2S	Public	2.01	0.92	1.39	0.64
1a.	Reinforced Concrete; 2 storied First floor	RC 2S (1F)	Public	2.83	1.28	1.60	0.73
1b.	Reinforced Concrete; 2 storied Second floor	RC 2S (2F)	Public	1.18	0.55	1.18	0.55
2	Reinforced Concrete and Masonry ; 2 storied	RC-M 2S	Public	2.04	0.98	1.45	0.70
3	Reinforced Concrete; 1 storied	RC 1S	Public	3.05	1.27	1.18	0.56
4	Reinforced Concrete and Masonry ; 1 storied	RC-M 1S	Public	3.04	1.32	1.25	0.62
5	Masonry-CGI sheet roofed (C/S joint); 1 storied	M-C	Public	1.90	0.89	1.39	0.64
6	Reinforced Concrete; 2 storied	RC1 2S	Residential	2.97	1.36	2.23	1.03
6a.	Reinforced Concrete; 2 storied First floor	RC1 2S (1F)	Residential	4.24	1.92	2.74	1.25
6b.	Reinforced Concrete; 2 storied Second floor	RC1 2S (2F)	Residential	1.73	0.82	1.73	0.82
7	Reinforced Concrete and Masonry ; 2 storied	RC-M1 2S	Residential	3.23	1.57	2.34	1.13
8	Reinforced Concrete; 2 storied	RC2 2S	Residential	2.88	1.33	2.23	1.15
8a.	Reinforced Concrete; 2 storied First floor	RC2 2S (1F)	Residential	4.22	1.93	2.87	1.31
8b.	Reinforced Concrete; 2 storied Second floor	RC2 2S (2F)	Residential	1.62	0.76	1.62	0.76
9	Reinforced Concrete and Masonry ; 2 storied	RC-M2 2S	Residential	2.93	1.43	2.39	1.15
10	Masonry-CGI sheet roofed (C/S joint); 1 storied	M-C1	Residential	2.57	1.22	1.95	0.93
11	Masonry-CGI sheet roofed (C/S joint); 1 storied	M-C2	Residential	2.80	1.33	2.04	0.97
12	Masonry-Tile roofed(mud joint); 2 storied	M-T(M) 2S	Residential	2.49	1.29	1.84	0.97
12a.	Masonry-Tile roofed(mud joint); 2 storied First floor	M-T(M) 2S (1F)	Residential	3.49	1.78	2.19	1.13
12b.	Masonry-Tile roofed(mud joint); 2 storied Second floor	M-T(M) 2S (2F)	Residential	1.52	0.83	1.50	0.80
13	Masonry-CGI sheet roofed(mud joint); 2 storied	M-C(M) 2S	Residential	2.45	1.28	1.80	0.95
13a.	Masonry-CGI sheet roofed(mud joint); 2 storied First floor	M-C(M) 2S (1F)	Residential	3.41	1.75	2.11	1.10
13b.	Masonry-CGI sheet roofed(mud joint); 2 storied Second floor	M-C(M) 2S (2F)	Residential	1.52	0.83	1.50	0.80

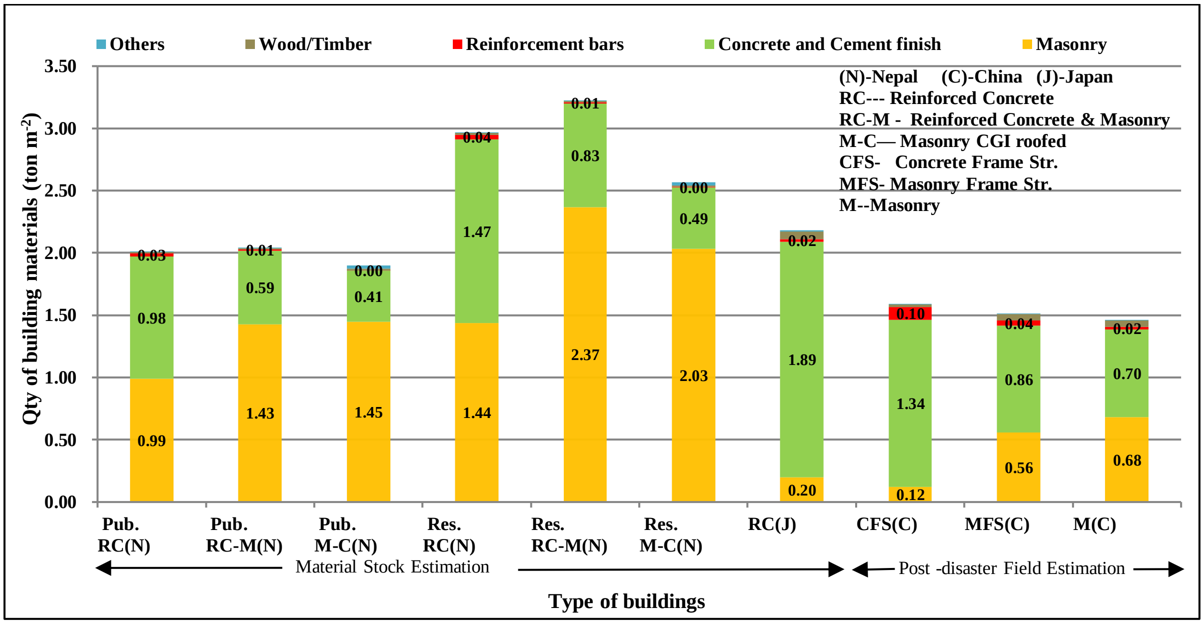


Figure 2-3: Comparison of total and individual building waste per m^2 in Nepal, Japan and China

The total amount of building materials used in buildings of Nepal, Japan and China with similar structural type was different. The proportions of masonry in buildings of Nepal are higher as bricks are used extensively in walls, pillars, and foundations whereas proportion of concrete is more in buildings of Japan and China. Traditional buildings in Nepal are characterized by thick walls, causing them to have a higher unit generation rate. Rubble masonry walls are as thick as 450 mm, while brick masonry walls in traditional buildings range from 360 to 600 mm thick. Infill walls for RC framed buildings are 230 mm thick in Nepal [25]. In Sichuan China, masonry walls are 180 to 240 mm thick [26]. In Japan, walls are 200 to 300 mm thick for masonry less than 5 m long, and only up to 190 mm for reinforced masonry [27]. The reason for higher quantity of concrete in buildings in Japan and China might be due to use of concrete in foundations, precast walls, and as blocks used extensively in the buildings.

2.3.2.2 Comparison of building waste generation rates in different countries

Unit generation rates including and excluding the foundation materials are calculated for different building types in Nepal. Comparison of unit generation rates above and below the foundation from different types of buildings in Nepal, China, and Japan (3 cases) are shown in Figure 2-4. Material stock estimation was used in current study for buildings in Nepal and the study for buildings in Japan for building material stock in 2000 AD by Nagaoka et.al, 2009 [28]. Post-disaster field estimation was used in Xiao et.al, 2012 [3] for a study in China following the Wenchuan earthquake in 2008 and for two studies in Japan by Takatsuki et.al, 1995 [29] and Hyogo, Prefecture data [30] after the Kobe earthquake in 1995.

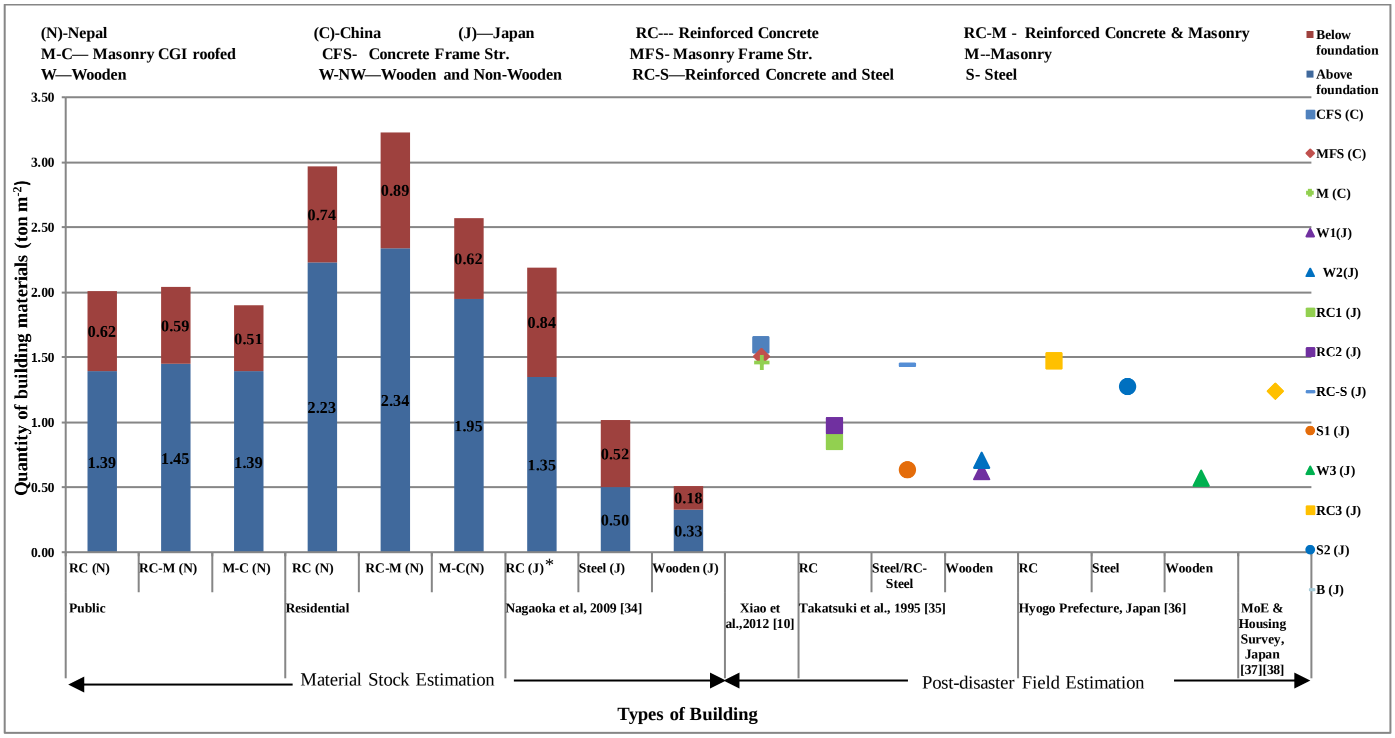
The overall unit generation rates for buildings in Nepal were larger than those for buildings in Japan and China. RC buildings in Japan generated 2.19 ton m^{-2}, which was higher than the unit generation from public RC buildings in Nepal, but lower than that from residential RC buildings in Nepal. The largest unit generation rates were found for all buildings in Nepal and RC buildings in Japan [28] than did the buildings in China [3] or other buildings in Japan by Takatsuki et.al, 1995 [29] and Hyogo, Prefecture [30].

The unit generation rates estimated from material stock, excluding the foundation, for public RC buildings of Nepal (1.39 ton m^{-2}) and RC buildings of Japan (1.35 ton m^{-2}) [28] were similar to the field estimated unit generation rates for concrete frame structure (CFS) buildings in China (1.59 ton m^{-2}) [3] and RC buildings in Hyogo Prefecture, Japan (1.47 ton m^{-2}) [30].

When comparing unit generation rates for the Nepalese public buildings RC(N), RC-M(N), and M-C(N) (excluding foundation materials) with the structurally similar CFS(C), MFS(C), and M(C) buildings in China, the unit generation rates for buildings in China were slightly larger than those for all building types in Nepal.

In Japan, unit generation rates for wooden buildings ranged from 0.51 to 0.71 ton m^{-2}, while those for steel buildings were 0.63 to 1.27 ton m^{-2}, and those for RC buildings were 0.85 to 1.47 ton m^{-2}. According to the information of Hyogo Prefecture, Japan [30] the unit generation rates ranged from 0.57 to 1.47 ton m^{-2}. Also according to Ministry of Environment[31], the quantity of building waste generated from the fully damaged building is estimated at 117 ton per house, and according to Housing and Land Survey of Japan [32]; the average floor area for dwellings in Japan is 94.42 m^2. Thus, the average value of unit generation for residential buildings in Japan was calculated to be 1.24 ton m^{-2}.

Results from the study of RC buildings in Japan in 2000 AD [28] were compared with those from the current study in Nepal because, in both cases, the unit generation rates were based on the material stock estimation method, with separate values for above and below the foundation. All buildings in Nepal and RC buildings in Japan [28] had the highest unit generation rates when including the foundation. RC buildings in Japan are mainly public buildings, so they are best compared with the public RC buildings in Nepal. The RC buildings in Japan [28] had a slightly higher unit generation rate, at 2.19 ton m^{-2}, than did public RC buildings in Nepal, at 2.01 ton m^{-2}. Unit generation rates differed depending on the building type and utility and the estimation method employed.



* For comparison of RC buildings with Nepalese RC buildings, data of RC buildings of Japan in 2000 AD is taken. It is because as the data of RC buildings in Nepal in 1981 or before was not available for no or very few RC buildings in Nepal at that time.

Figure 2-4: Comparison of total building waste per m^2 in Nepal, Japan and China

2.3.3 Volume of building waste generation per unit area indifferent countries

Volumetric unit generation rates (m^3 m^{-2}) from different types of buildings in Nepal, Japan, and Sri Lanka are shown in Figure 2-5. The volume of generated waste for buildings in Nepal was taken to be the same compacted volume as that of the materials used for construction. The actual volumetric unit generation rates during the process of dismantling of building could vary by dismantling methods and storage conditions of the building debris. Available data for volumetric unit generation rates for buildings in Japan(Takatsuki et al., 1995) [29]; buildings in Japan by Hyogo Prefecture [30] and Sri Lanka (Karunasena et al., 2012)[33] utilize the bulk volumes per unit area removed during demolition of the damaged buildings after the disaster. Wooden buildings in Japan had the largest volumetric unit generation rates while steel buildings in Japan had the smallest [29]. In Nepal, volumetric unit generation rates for RC buildings including and excluding the foundation were 0.92 m^3 m^{-2} and 0.64 m^3 m^{-2}, respectively, for public buildings, and were 1.35 m^3 m^{-2} and 1.03 m^3 m^{-2}, respectively, for residential buildings, while RC buildings in Japan had values ranging from 0.75 m^3 m^{-2} to 1.2 m^3 m^{-2} [29][30]. Public masonry buildings in Nepal had values of 0.89 m^3 m^{-2} (including the foundation) and 0.64 m^3 m^{-2} (excluding the foundation), while residential buildings had values of 1.28 m^3 m^{-2} (including the foundation) and 0.95 m^3 m^{-2} (excluding the foundation). Masonry buildings in Sri Lanka had a value of 0.73 m^3 m^{-2}, which is similar or more to the rates for public masonry buildings in Nepal excluding the foundation. Values of wooden building ranged from 0.84 $m^3 m^{-2}$ to 1.77 $m^3 m^{-2}$ in Japan and that of steel buildings from 0.46 $m^3 m^{-2}$ to 0.96 $m^3 m^{-2}$ in Japan [29] [30].

The volumetric unit generation rates for the buildings of Nepal could be higher than the calculated value if the volume is measured for the debris generated from dismantling of buildings after disaster. Also, the value of volumetric unit generation rates for the buildings of Nepal could be lower if compared with the values calculated by post-disaster field estimation method.

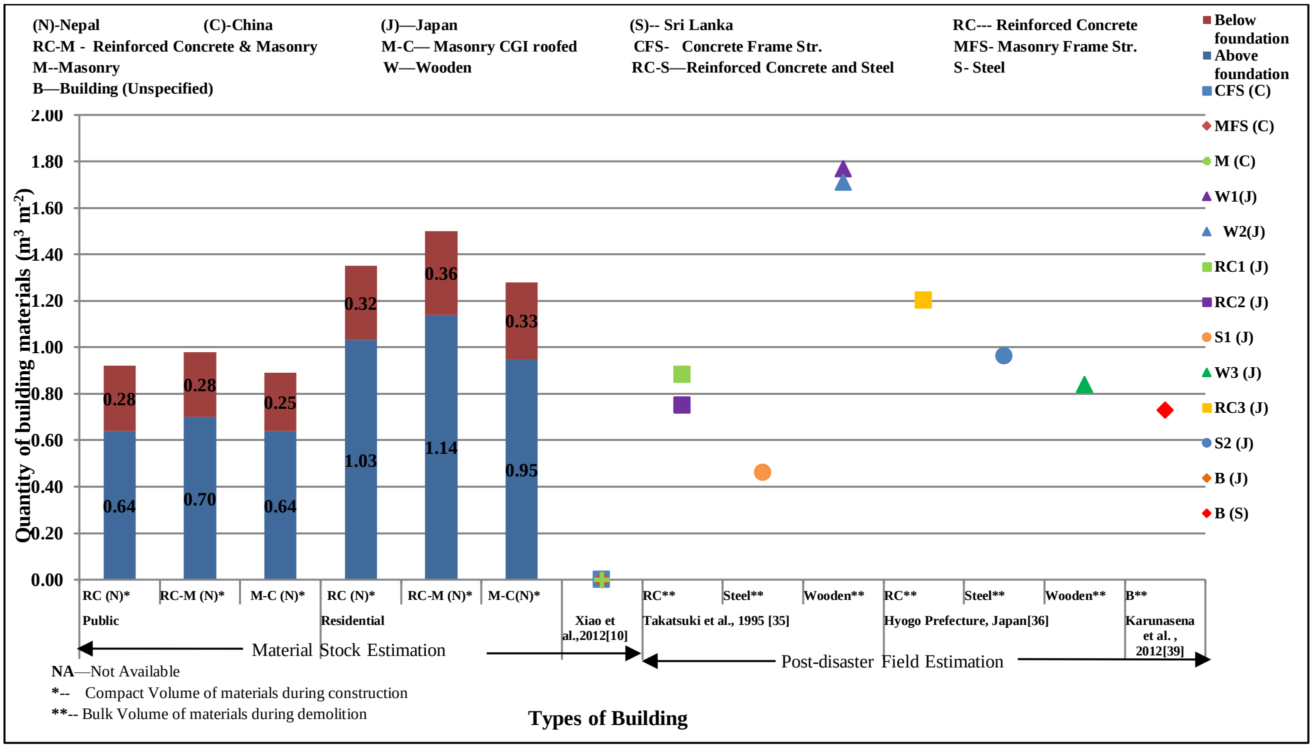


Figure 2-5: Comparison of total building waste volume per m^2 in Nepal, Japan and Sri Lanka

2.4 Conclusion

The unit generation rates were different for buildings with differing structural types or number of stories. A large fraction of the waste included brick and concrete for all buildings. The unit generation rates by weight were higher in Nepal than they were for similar buildings in China and Japan. Unit generation rates depend upon the method of estimation i.e. material stock estimation and post-disaster field estimation. Unit generation rates for the public RC type building in Nepal and Japan excluding the foundation materials were close to the similar building in China. Similarly, the unit generation rates for wooden buildings in Japan were nearly equal using different estimation methods. The unit generation rate in volume was higher in Japan than it was in Nepal and Sri Lanka. In the future, the estimates developed here can be used for determining exact quantities of individual and total building waste from damaged buildings with the data of structural types, floor area, number of story and actual treatment potential ratio for the specific treatment option and final management of building waste. The unit generation rates presented here will be most helpful for central and local governments, civil engineers, city planners, builders, and recyclers etc.

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Chapter 3

Disaster waste management and disposal status of debris in Kathmandu, Nepal, field studies after the Gorkha Earthquake

3.1 Introduction

3.1.1 Disaster waste in Nepal and management in Kathmandu Valley

According to a report prepared by the International Organization for Migration (IOM) and the Government of Nepal, the post-earthquake debris management strategic plan specified that nine out of 83 open places were marked for debris management in the core city area of Kathmandu Valley [1]. After the Gorkha earthquake, a large quantity of building debris was expected to be generated from the core city area of Kathmandu Valley (Kathmandu City and Lalitpur city), which the government planned to dump on the old limestone quarry site of Himal Cement Factory in Chobhar, approximately 7 km south of the core city area [2]. Despite the government plan, no debris had been deposited in the Chobhar area two years after the Gorkha Earthquake. The government was worried about finding a larger and safer area for its disposal but, instead, the debris was managed within the city on river banks, adjacent to the ring road (on open land), in land development projects, and through the reuse of building materials. There were no data or information from house owners, demolition contractors, or private developers provided to government agencies on the volume of debris generated, transported and disposed, or reused. Government agencies therefore did not obtain sufficient information about exact disposal methods and quantities of disaster debris generated in the core city area due to prioritizing issues other than the disposal of building debris after the main relief, recovery, and rehabilitation efforts. Thus, for the effective management and disposal of debris, it is important to determine the current debris management practices, disposal locations, and quantities of debris waste generated within the core city area.

3.1.2 The aim of the study

The aim of this study was to investigate building debris management practices after the earthquake relief, recovery, rehabilitation, and reconstruction phases, as well as actual methods of building waste disposal in the Kathmandu Valley, Nepal, two years after the earthquake. An additional aim was to estimate the amount of debris deposited in the core city area of Kathmandu Valley (Kathmandu Metropolitan City and Lalitpur Sub-Metropolitan City).

3.2 Materials and methods

The research is divided into three parts. The methodologies include: a case study of debris management practices in Kathmandu Valley; quantification of building debris generation plus recycling quantities; and quantification of debris waste disposed in the core city area of Kathmandu Valley.

3.2.1 Field surveys on building debris management practices in Kathmandu Valley

The study was based on site visits and direct interactions with different stakeholders directly associated with building waste management performed on 11–20 March 2017, in selected cities of Kathmandu Valley. Kathmandu Metropolitan City (KMC) and Lalitpur Sub-metropolitan City (LSMC) constitute the core city area of Kathmandu Valley, and Bhaktapur City and other small growing cities such as Sakhu in Shankharapur Municipality, Lubhu in Mahalaxmi Municipality, and Kirtipur Municipality in Kathmandu Valley comprise the out of core city area of Kathmandu Valley (i.e., outside of the core city area). Additional field visits to small towns such as Khokana and Bungmati, damaged heritage sites, and the Chobhar area (initial government-proposed debris disposal area) were made. The interactions and field visits were supported by OXFAM Nepal and their local NGO partner. Similarly, interaction and data collection were conducted with governmental officials of Kathmandu Valley related to disaster waste management. A map of Kathmandu Valley and field visit locations is shown in Figure 3-1. Further details of the case studies are provided in Section A of Appendix.

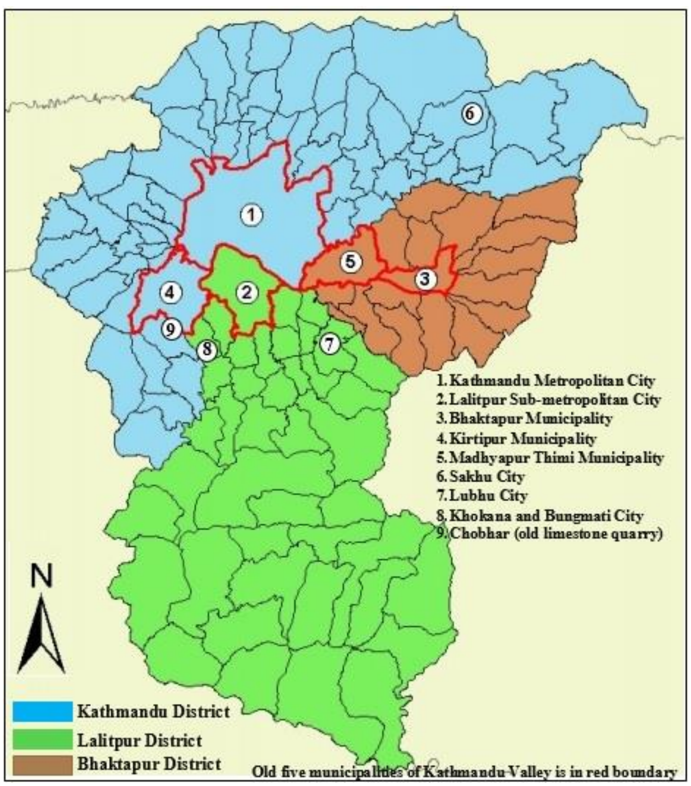


Figure 3-1: Map of Kathmandu Valley and field visit locations [3]

3.2.2 Debris waste quantification from damaged buildings

The total potential amount of building debris was calculated from data of the Central Bureau of Statistics in Nepal [4] for damaged buildings (floor area, number of stories, and building type) and the unit generation rates (excluding foundations) for each damaged building[5]. Unit rates not mentioned in Poudel et al., 2018 [5] were calculated using the same method and values of unit generation rates for composite building types as those in Poudel et al., 2018 [5] for each floor according to their respective building type. The types of buildings and unit generation rates for each floor of different building types are summarized in Table 3-1.

These unit generation rates for floors of different building types and the floor area of each story gives the quantity of each building and the sum of damaged buildings provides the potential total building waste generated. The CBS 2017 [4] data provide information about the current situation of each damaged building under survey in different categories: a) damaged - rubble cleared, b) damaged - rubble uncleared, c) covered by landslide, d) damaged - rubble cleared - new building constructed, e) damaged - not used, f) damaged - used in risk, g) damaged - repaired and used, and h) not damaged. The quantity of building waste calculated from the above method are further categorized in terms of debris management as a) already cleared, b) left for clearing, and c) no need for clearing.

Table 3-1: Unit generation rates of different buildings for total debris calculation

S.N.	Type of building [4]	Equivalent building type [5]	Symbol	Unit generation rates (tons/m^2) First floor	Unit generation rates (tons/m^2) 2nd and upper floors	Remarks
1	Mud-mortar stone/brick, heavy roof	Masonry-tile roofed (mud joint)	M-T(M)	2.19	1.50	[5]
2	Mud-mortar stone/brick, light roof	Masonry-CGI roofed (mud joint)	M-C(M)	2.11	1.50	[5]
3	Cement-stone/brick RC roof	Reinforced concrete and masonry	RC-M	2.65	2.05	Calculated by same method as [5] for individual floors
4	Mud-mortar stone/brick RC roof	Masonry-CGI roofed (mud joint) + reinforced concrete and masonry	M-C(M) + RC-M	2.11	2.05	Combination of different building types in each floor; applying respective unit rates
5	Cement-stone/brick heavy/light roof	Reinforced concrete and masonry + masonry-CGI roofed (C/S joint)	RC-M + M-C	2.65	2.00	Combination of different building types in each floor; applying respective unit rates
6	RC building with RC roof	Reinforced concrete	RC	2.74	1.73	[5]

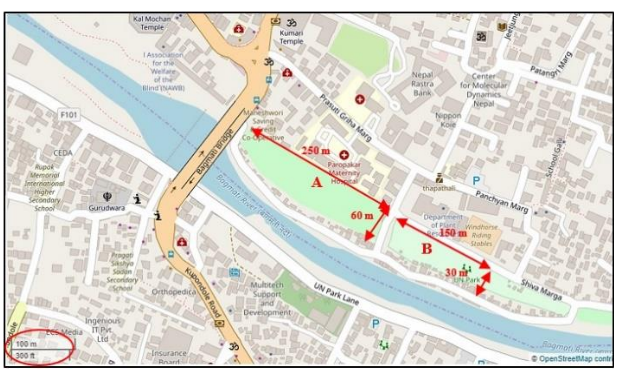
RC--- Reinforced Concrete **RC-M**---- Reinforced Concrete and Masonry **M-C**----Masonry and CGI roofed
M-T(M)--- Masonry and Tile roofed (joint in Mud mortar) **M-C(M)**--- Masonry and CGI roofed (joint in Mud mortar)

Unit generation rates of individual building materials for each building type were used to calculate the total quantity of individual building materials of the total debris already cleared. The total quantity and proportion of each building material were calculated by the above process. From surveys and interviews with experts, the reuse or recycle potential of different building materials were derived, which were case specific and area specific. The range of reuse or recycle rates with the individual total quantities of already cleared buildings gives the range of the total quantity of building materials reused or recycled.

3.2.3 Debris waste quantifications at destination core city points

After demolition of damaged buildings, house owners and contractors salvaged the usable building parts then other debris from demolished damaged buildings was disposed within the core city area of Kathmandu Valley along river banks (Bagmati, Bishnumati river), in vacant open land along the ring road, or in places such as *Tinkune* (in Kathmandu city, named after the triangle formed in vacant land by the alignment of roads; shown in Figure 3-2) in Kathmandu. There may then be further diversion of building debris through disposal in isolated vacant land, land development projects, or the foundations of newly constructed buildings. However, quantification of deposited building debris was attempted for the major open spaces or probable areas for the temporary disposal and management of debris waste identified from the Environmental Impact Assessment (EIA) report and Solid Waste Management Technical Support Centre (SWMTSC) report. The amount of disaster debris deposited haphazardly within the core city area of Kathmandu Valley was calculated from the disposal points according to the area and average height of the deposit. The volumetric quantity of disposed building debris is given by the following equation.

Volume of disposed building debris = Deposited area x Average height of debris deposition….. (1)



Source: Open Street Map

Point 11. Near police station behind maternity hospital
Total area = 19500 m^2

Source: Open Street Map

Point 12. Open space in Tinkune (triangle)
Total area = 17320 m^2

Figure 3-2: Calculation of building debris disposal area (*map taken from Open Street Map*)

To quantify the amount of debris at different destinations, information of open spaces available for emergency debris disposal is employed for the calculation. The EIA report on "post-disaster debris collection, disposal and management sites" submitted to IOM suggests nine points in the core city area with effective area available for debris disposal (Section B in Appendix) [6]. A report entitled "Disaster Waste: Addressing the Challenges in Nepal" by SWMTSC, Nepal, identifies 18 temporary sites and 2 large scale debris disposal sites (Section C in Appendix)[7]. Of the nine points suggested by the EIA report, seven points are considered for calculation. The remaining two points suggested in the report were not used, which were a public-park and an abandoned waste water treatment plant. Similarly, only five points out of 18 points were considered from the SWMTSC report. This was because, of the thirteen points not considered, one point had already been included in EIA report submitted to IOM, six points were found to be not in use during field visits, and the remaining six points were small temporary points for collection before transfer to second temporary points; thus no debris is currently left at those points.

The effective area of disposal points suggested by the EIA report are given in the report and the area of points suggested by the SWMTSC report were calculated with the help of Google maps (using the map scale and approximate dimensions to calculate the area). An illustration of the calculation of disposal area is given in Figure 3-2. For the purpose of calculation, the average height of the deposit was assumed to be 1.75 m (average deposition height ranging from 1.25–2.25 m) and only 80% of the area used for deposition was assumed to be occupied. The quantity of building debris is obtained by the following equation.

Quantity of building debris (tons) = Volume of debris x Density of building debris ………….. (2)

3.3 Results and discussion

Many buildings in Kathmandu Valley were damaged by the 2015 Gorkha earthquake; the status of building damage is shown in Table 3-2. The damaged buildings produced large amounts of building debris, of which most remained uncleared two years after the earthquake. The debris management situation of the core city area of Kathmandu Valley is shown in Figure 3-3. Within the figure, 'Disposed' refers to the removal of the debris from the damaged site by the owner of the damaged building, which is the permanent type of solution in terms of debris removal and deposition, however, the recoverable materials were still collected by other people from the disposal area who needed them. The detailed of current state of debris waste generation and management is given in Section D of Appendix.

Table 3-2: Building status in Kathmandu Valley after the 2015 Gorkha earthquake [4,8]

Building status in Kathmandu Valley	Core Kathmandu Valley (Nos.)	Out of core Kathmandu Valley (Nos.)	Total (Nos.)
Fully damaged	4,462	41,076	45,538
Partially damaged	9,999	54,840	64,839
Undamaged	294,412	208,817	503,229
Total	308,873	304,733	613,606

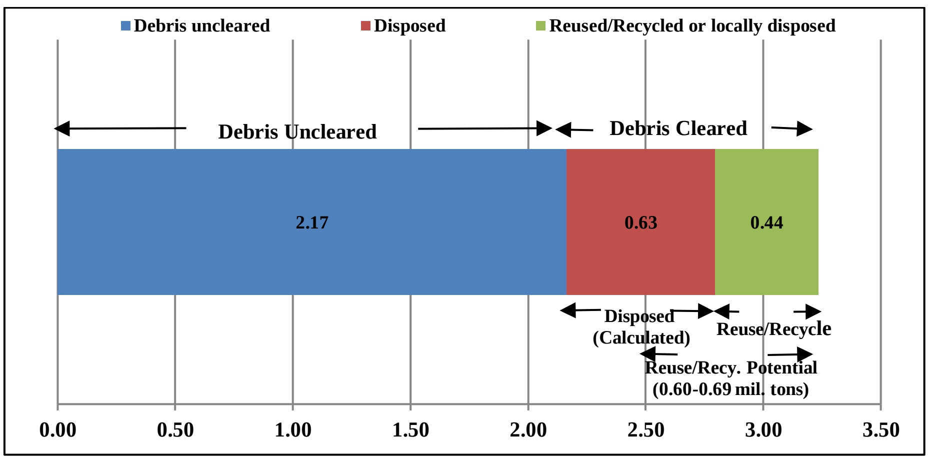


Figure 3-3: Debris management situation in the core city area of Kathmandu Valley (mil. tons)

3.3.1 Management of building debris in Kathmandu Valley

Disposal of disaster debris in Kathmandu Valley employs the open dumping method and includes no facility for the treatment of wastewater leaching through the debris material. In some cases, disposal points were identified and allocated by the municipalities; in other cases, individuals dispose of the waste themselves. The management of building debris in Kathmandu Valley can be categorized into five methods, described as follows:

3.3.1.1 Reuse/recycling of individual building materials:

Debris generated from the disaster were used directly after cleaning or the intermittent products were utilized as resources after certain processing. It was found that people segregated some usable building materials for reuse and sold some to scrap dealers and building contractors. Building materials such as bricks were used for new construction after cleaning and collecting whole and half-broken bricks.

Similarly, stone debris were reused for new construction and foundations because of its strength. Wood or timbers were used in the form of door/window frames and shutters in new construction, and damaged wooden parts such as posts and beams of old buildings were reformed to make new building materials. Used timber has good salvage value in Nepal. Metals in debris were separated and sold to scrap collectors, which finally went for recycling.

3.3.1.2 Thermal recovery:

Wooden materials not suitable for reuse or reform and remains of wood processing such as wood dust and wooden scraps were used as fuel wood. No wooden materials go to the final disposal.

3.3.1.3 Reuse of mixed debris as filling materials:

Most of the buildings damaged in Kathmandu Valley after the Gorkha earthquake were mud-bonded, brick structures with mud plaster in the floor and walls. In addition, damage was more severe in buildings with sun-dried brick masonry and mud mortar. A large quantity of soil (mud) was generated, which was then used in filling and levelling works on land. Concrete and plaster was not recycled in Kathmandu due to very nominal generation or generated in the core city area but reuse as filling material in minimal quantity and discarded mostly; however, it can also be used as road gravel mixed with broken piece of bricks, broken stones, and soil on earthen roads in the out of core city area and roads linking rural areas with the city. Mixtures of brick pieces, stone, concrete and soil were used as filling materials in the foundations of newly constructed buildings and the backfill of road structures.

3.3.1.4 Reuse of mixed debris for land development:

Some disaster debris in Kathmandu Valley were used directly in land reclamation works. Debris employed for land reclamation were used without prior treatment for harmful substances. Land development projects in the area outside of the ring road and small towns made use of building debris for filling, levelling of land, and sale for building construction. Small private land owners also collected debris for filling, levelling, and building construction. Filling of soil-excavated pits in brick factories using mixed debris mix was also conducted to improve the land.

However, building debris were disposed in governmental land like low lying area or bank of river as it was found vacant. Typically, government land was not used for heavy construction after filling and levelling the land but was converted into public spaces such as playgrounds and parks. After filling, river banks and vacant land along the road side were developed into gardens and walking pavements in some cases.

3.3.1.5 Temporary collection areas:

Vacant government land such as common courtyards, playgrounds, and parks in dense settlement areas was often used as temporary collection points during the emergency period after the disaster for debris removal. In addition, dried traditional pond areas were used for the collection of building debris in one city in Kathmandu Valley.

3.3.1.6 Final disposal:

Final disposal of the disaster debris in Kathmandu Valley was conducted in various ways. In the out of core city area, debris were disposed in public low-lying land, vacant land, or down the cliff slope areas allocated by the municipality after the disaster. In the core city area, building debris were mostly disposed of on river banks and open vacant land such as along the ring road.

The initial stage of debris disposal proposed by the municipalities and the current disposal situation is given in Table 3-3. During the field study, it was found that building debris was disposed in the different areas mentioned above, within 2–5 km from the point of waste generation. Hazardous waste like asbestos, mercury, organic solvents, etc. might have been present in very small amounts; however, in our interviews in Kathmandu Valley, no serious impacts were mentioned by the personnel of concerned agencies. The random deposition of building debris at different locations in Kathmandu is shown in Figure 3- 4.

Table 3-3: Building debris management in municipalities of Kathmandu Valley

Municipalities	**Proposed final disposal**	**Current debris management situation**
Kathmandu Metropolitan City (core city)	Dispose at Chobhar (Old Limestone Quarry);	• Foundation filling • River banks • Lowland and side of ring road
Lalitpur Sub-Metropolitan City (core city)	Dispose at Chobhar (Old Limestone Quarry);	• Foundation filling • River banks • Lowland and side of ring road
Bhaktapur Municipality (out of core city)	Municipality designated area	• Foundation filling and surface of earthen roads • Soil-excavated pits of brick factories • Land development projects • Low lands and open vacant lands
Kirtipur Municipality (out of core city)	Municipality designated area	• Road expansion project • Land development projects • Old dry traditional ponds • Lowland and down the cliffs
Other Municipalities (out of core city)	Municipality designated area	• Lowland and land development projects • On earthen roads • Lowland and down the cliff

Details of current disposal methods are provided in Appendix (Section E)

(a) (b) (c)

Figure 3-4: (a) Debris fill on a cliff slope, Bhajangal Kirtipur, (b) debris collection in a playground, Kirtipur, and (c) debris from archaeological sites in Tundikhel, Kathmandu

From the results, it is clear that building debris generated within the core city area of Kathmandu Valley was disposed of using various methods that did not include disposal to the government designated area.

In Aceh after the 2004 tsunami, approximately 400,000 m^3 of tsunami-related waste was dumped into rice fields, fish ponds, and other open areas [9]. Likewise, illegal dumping of debris occurred on the banks of Rivière Grise, stretching from La Viste national park, south of Port-au-Prince, to the capital's bay after the 2010 Haiti earthquake [10], and in addition for debris collection, government set a plan with 60 percent of the sites aside for roads, buffer areas, and treatment operations [9]. Debris clearance and disposal after the Great Hanshin-Awaji Earthquake 1995 was mostly conducted in coastal areas [11]; however, after other earthquakes, such as the 2011 Great East Japan Earthquake and 2016 Kumamoto earthquake, generated debris were collected from the sites of origin designated as temporary sites for sorting and recycling and final disposal at the designated landfill site.

Debris collection and disposal in developing countries conducted immediately after a disaster is predominantly unplanned and disorganized but after the Great Hanshin-Awaji Earthquake, 1995, the non-coordination of debris management entities adversely affected recycling and disposal. Similarly, weak planning and coordination of debris management after the 1999 Marmara earthquake in Turkey led to extensive dumping of recyclable materials after the debris became commingled with soil, clothes, wood, and even hazardous waste in some cases, requiring expensive secondary sorting processes [9]. In the case of the 2015 Gorkha Earthquake in Nepal, the government could not strictly control the disorganized disposal of building debris within the core city area of Kathmandu Valley area after the earthquake.

The time required for preparation of a complete debris management plan varies for developed and developing countries; it took approximately 1 to 1.5 months in the U.S. after Hurricane Katrina yet close to 2 years in Aceh after the tsunami [9]. After the 2015 Gorkha Earthquake in Nepal, the action plan for debris management was finalized in 8–9 months [12]; however, this plan had implementation difficulties due to a lack of sufficient funds, a skilled work force, tools, and equipment, and due to this aspect being the lowest priority of the government.

3.3.2 Total generated building debris and management in the core city area of Kathmandu Valley

From our calculation, a potential of 3.23 million tons of building debris was generated from the damaged buildings in the core city area of Kathmandu Valley, of which 1.07 million tons has already been cleared two years after the Gorkha earthquake and 2.17 million tons has yet to be cleared (as shown in Figure 3-5). The potential amount of debris generated from Kathmandu Metropolitan City alone was 2.07 million tons (64% of total) and that of Lalitpur Sub-metropolitan City was 1.15 million tons (36%). The majority of damaged buildings in Kathmandu valley were old buildings consisting of bricks bonded with mud mortar and other buildings with masonry as a major building component. The proportion of building materials in already cleared building debris of the core city area of Kathmandu Valley is shown in Figure 3-6 where masonry represented the highest proportion (75%). The proportions of other materials are as follows: concrete 10.37%, soil (mud) 10.48%, metal 0.42%, wood timber 3.81%, tile 0.25%, and others 0.01%. The quantity of disaster debris in Kathmandu Valley after the 2015 Gorkha earthquake was 4 million tons, as reported by the government [7]; however, from our calculation, the potential disaster waste generated in Kathmandu Valley after a study of damaged buildings was 19.27 million tons. Similarly, the disaster waste generated in the 2008 Wenchuan Earthquake was reported to be 20 million tons [13], but a later study on damaged buildings and potential disaster waste generated by the earthquake yielded a figure of approximately 380 million tons [14].

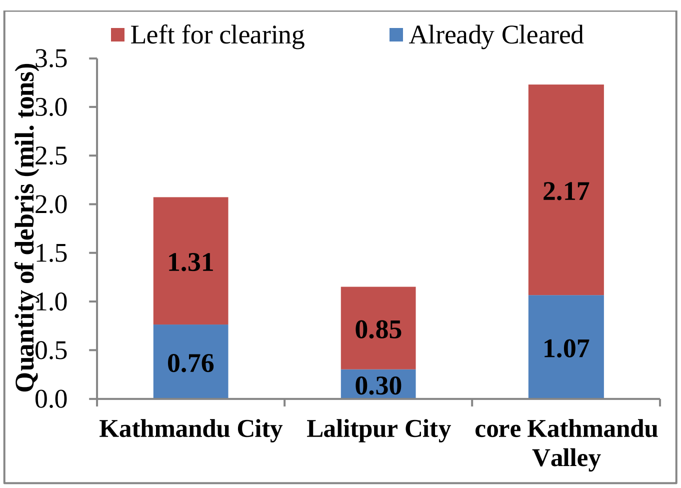


Figure 3-5: Building debris generation in the core city area of Kathmandu Valley

(Calculated from the sum of CBS, 2017 data on damaged buildings (area, story, and type) and unit generation rates for each damaged building [5]

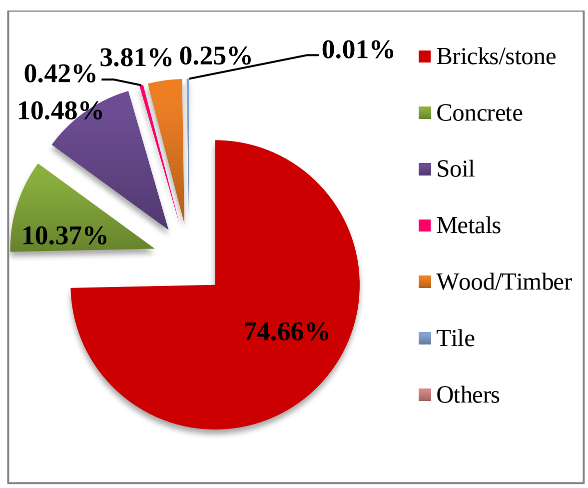


Figure 3-6: Proportion of building materials of already cleared building debris in the core city area of Kathmandu Valley

Thus, the exact quantity of disaster debris generated in less developed countries is not rigid and can vary substantially. The value of 20 million tons reported for the 2008 Wenchuan earthquake was cited from a photo journal in many studies that did not describe the exact method of quantification and was likely an assumption based on the emergency debris removal period. Moreover, for the 2015 Gorkha earthquake, the government report employed very low unit generation rates and average building sizes. A later calculation was performed using unit generation rates [5] and the exact size and condition of each damaged building to produce a more accurate value. Also, delayed demolition and disposal of disaster waste in developing countries leads to a lower estimate of disaster waste than that actually generated. In Nepal, the frequency of large disaster is in the interval of 80 years and the planning for disaster waste have enough time for the preparation of the next disaster for the effective treatment and management. The waste generated by the Gorkha earthquake were mostly from the mud mortar jointed brick masonry buildings which were damaged around 85% and most of the waste was brick and soil. For the time being, the disaster waste was disposed by various methods in nearby area. However, for the next disaster, the proportion of the type of the disaster waste might be different as the policy of government enforced to construct stronger buildings with implementation of building codes compared to mud bonded masonry buildings. Similarly, the land available for haphazard disposal of disaster waste available for this time might not be available for the future, so that reuse and recycling of disaster waste in maximum quantity and appropriate place for the safe disposal of waste should be identified during the planning process. Future, disaster waste management should include improved disaster waste management response with greater environmental concern.

3.3.3 Recovery and reuse of building materials in Kathmandu Valley

The main building materials in debris were brick, stone, wood, metal, concrete, cement plaster, soil, etc. The recovery and reuse of building materials was very important in Kathmandu Valley, and is shown in Table 3-4 for different locations. The rates of reuse or recycling were area specific and case specific. In core areas, debris should be removed first and many usable things will be discarded but salvaging of material should occur in areas with available space.

Most reusable or recyclable materials to be salvaged from damaged, old, mud-bonded masonry buildings were poor in quality, non-standard in size, and broken or destroyed. In Kathmandu Valley, brick reuse can be up to 5–70%, stone reuse was 5%–90%, soil reuse/recycling was 15–80%, wood reuse/recycling was 50–90%, metal recycling was 20–90%, and concrete and plaster recycling was zero. Similarly, in the Kathmandu core city area, the reuse/recycling of brick was 60–70%, stone 80–90%, soil 80%, wood 70–90%, metal 20–100%, and concrete/cement plaster was zero.

Table 3-4: Reuse/recycling rates from survey in Kathmandu Valley

Area	Building materials and their reuse/recycling ratio (%)							Remarks
	Brick	Stone	Concrete	Wood	Metal	Plaster	Soil	
	(a)	(a)	(a)	(a)	(a)	(a)	(c+d)	Of all management option of materials in Kathmandu as in Chapter 3.3.1 {(a+b+c+d+e+f)}
Sakhu, Kathmandu	0-5%	80-90%	0%	80-90%	0-20%	0%	15-20%	out of core city
Lubhu, Lalitpur	10%	—	0%	50%	90%	0%	—	out of core city
Kathmandu Metropolitan City	60%	—	0%	70%	100%	0%	80%	core city
Kathmandu / Lalitpur City	65-70%	80-90%	0%	80-90%	20%	0%	80%	core city
Sakhu, Kathmandu	20-30%	5-10%	0%	70-80%	70-80%	0%	80%	out of core city

(Based on information from engineers, ward chiefs and divisional engineers working in Kathmandu Valley)

Debris management options as in Chapter 3.3.1

(a) Reuse/recycling of individual building materials (b) Thermal recovery (c) Reuse of mixed debris as filling materials
(d) Reuse of mixed debris for land development (e) Temporary collection areas (f) Final disposal

The rates in table considers only,

For Brick, Stone, Concrete, Wood, Metal and Plaster: *a of (a+b+c+d+e+f)*, as in Chapter 3.1. Reused directly or recycled from different debris management options.

For Soil: *(c+d) of (a+b+c+d+e+f)*, as in Chapter 3.3.1. Used as filling works and land development works from different debris management options.

The generation of concrete waste is mainly from the RC buildings and from CBS, 2017 damage survey of Kathmandu Valley it was found that 88% of total damaged buildings were mud bonded masonry buildings and only 4.5% were RC buildings and among already cleared damaged buildings till damage survey, 95% buildings were mud bonded buildings and 1% RC buildings. Also, damages on RC buildings were in core city which need to be removed out of the dismantling area. Thus the concrete generation as debris was very less and found discarded mostly with very nominal use in Kathmandu Valley.

According to calculations of the 1.07 million tons of building debris already cleared and the proportion of each building material (Figure 3-6) with reuse/recycling rates of building materials in the core city area of Kathmandu Valley, the overall reuse/recycling quantity of building materials ranged from 0.60–0.69 million tons, divided as follows: masonry (bricks/stone) 0.48–0.56 million tons, soil (mud) 0.09 million tons, total metal 0.001–0.005 million tons, and wood/timber 0.03-–0.04 million tons.

Additionally, the new constructions built after demolishing the old buildings were RCC framed buildings; hence, materials from the old buildings were not used and were mostly discarded. Bricks from cement-bonded masonry were also difficult to recover. Metals from RCC buildings were recoverable, especially from slabs, but those from pillars, beams, and foundations are discarded. To use building materials from demolished buildings, guidelines were under development by the Department of Urban Development and

Building Construction. To date, there have been no efforts or fixed plans made by the government to recycle building waste. Preparation for recycling and reuse of building materials is shown in Figure 3-7.

(a) (b) (c)

Figure 3-7: (a) Cleaning of old bricks for reuse, (b) reuse of old bricks in new construction, and (c) building materials for reuse

It was found that the reuse or recycling ratio of concrete in Kathmandu Valley to be zero but concrete is widely recycled with maximum percentage in the developed countries. It is to conserve the resource as well as to have less impact to the environment. The disaster waste in future might have more compared to this Gorkha earthquake, so future planning on the reuse/recycling of concrete waste should be planned with increasing reuse/recycling ratio of other waste as well. At present, the perception for not recycling were lack of recycling technologies, increased price for the recycled material, the recycling materials are not good in strength as the original material and abundant virgin materials in cheaper cost. However, government has to plan for effective management by maximizing the reuse or recycling of concrete by reducing the price of the recycled materials by subsidizing the production cost and enforcing the materials to be used as road base, non-structural parts of building, filling the foundations in buildings and land reclamation in both private and public works.

For developed countries such as European countries, the USA, or Japan, regulations for the recovery or reuse of building waste (either construction and demolition waste or building debris from disasters) were well established with adequate recovery facilities. Thus, European countries have the economic feasibility to recover up to 80‑90% of construction and demolition waste [15]. Similarly, the recovery rate for debris waste in Iwate and Miyagi prefectures after the 2011 Great East Japan Earthquake was 90% [16] and the recovery of debris after demolition following Hurricane Katrina in New Orleans was 48% [17]. However, in less developed countries, debris recovery rates are potential recycling rates rather than exact rates. After the 1999 Marmara Earthquake, Turkey, more than 90% of the original debris was recyclable but weak planning and coordination prevented this [9]. Similarly, 70–90% of the debris generated in the Gorkha Earthquake could have been reclaimed [18], yet the average potential reuse/recycling rate of building debris in the core city of Kathmandu Valley was calculated as 60% in this study.

3.3.4 Estimation of building debris at its destination in core city area of Kathmandu Valley

After revealing that no debris reached the Chobhar site designated by the government for disposal of disaster debris after the Gorkha earthquake, it was found that building debris was disposed of at major points within the core city area of Kathmandu Valley through various methods, as identified by the EIA report and SWMTSC report. Volumetric calculations of disposed building debris were made; the volume range and average volume of deposited building debris is shown in Table 3-5. Our calculations of the volume of disposed debris according to the given area of sites, a deposit height of 1.75±0.5 m, and an overall occupancy in disposal sites of 80% resulted in a total volume of disposed debris of 248900 to 448000 m^3 with an average volume of 349000 m^3. Below is the calculation for the total building debris quantity disposed within the core city area of Kathmandu Valley:

Table 3-5: Volume of building debris disposed within the core city area of Kathmandu Valley

S.N.	Temporary disposal site	Location	Available area (m^2)	Volume range (m^3)	Avg. volume (m^3)	Remarks
1	Bagmati Corridor 4	Kathmandu 12	10000	10000–18000	14000	EIA report; 1.75±0.5 m; 80%
2	Bagmati Corridor 5	Kathmandu 11	21000	21000–37800	29400	EIA report; 1.75±0.5 m; 80%
3	Bagmati Corridor 6	Kathmandu 34	3000	3000–5400	4200	EIA report; 1.75±0.5 m; 80%
4	Ringroad Maharajgunj Chabahil	Kathmandu 4,7&3	60000	60000–108000	84000	EIA report; 1.75±0.5 m; 80%
5	Ringroad Balkumari Gwarko	Lalitpur 7,8&9	30000	30000–54000	42000	EIA report; 1.75±0.5 m; 80%
6	Ringroad Gwarko Satdobato	Lalitpur 17 &15	33000	33000–59400	46200	EIA report; 1.75±0.5 m; 80%
7	Ringroad Satdobato Ekantakuna	Lalitpur 13, 14 &11	50000	50000–90000	70000	EIA report; 1.75±0.5 m; 80%
8	Open space near Dallu Susp. Bridge	Kathmandu 19	1020	1020–1836	1428	SWMTSC report; (50*12+7*60) from Google; 1.75±0.5 m; 80%
9	Open space near Kalimati Bridge	Kathmandu 13	1700	1700–3060	2380	SWMTSC report; (100*8+60*15) from Google; 1.75±0.5 m; 80%
10	Near compound of Banasthali School	Kathmandu 16	2400	2400–4320	3360	SWMTSC report; (200*12) from Google; 1.75±0.5 m; 80%
11	Near police station behind maternity hospital	Kathmandu 11	19500	19500–35100	27300	SWMTSC report; (250*60+150*30) from Google; 1.75±0.5 m; 80%
12	Open space in Tinkune	Kathmandu 35	17320	17320–31176	24248	SWMTSC report; (0.5*173.2*200) from Google; 1.75±0.5 m; 80%
			Total volume	248940–448092	348516	

Total average volume of building debris calculated from deposition areas on river banks, along the ring road, and in open spaces from Table 5 = **348,516.00 m^3**

Assumed bulk density of building debris = **1800 kg per m^3** [19],

Total building debris quantity = **0.627 million tons**

Thus, the total quantity of building debris deposited in the above sites ranged from 0.448 to 0.807 million tons. Of the 1.07 million tons of already cleared building debris in the core city area of Kathmandu Valley, it is clear that 0.63 million tons (59%) of building debris were disposed at different disposal sites (Table 3-5). Thus, the remaining 41% of building debris generated in the core city area of Kathmandu Valley in different disposal sites were diverted by the salvaging and recycling of usable and important building materials or the disposal of building debris by individual house owners or local demolition contractors in isolated areas in open vacant land, land development projects, or in the foundations of newly constructed buildings.

The total quantity of already cleared building debris in the core city area of Kathmandu Valley was 1.07 million tons, 0.448–0.807 million tons of which was disposed of with an average of 0.63 million tons (59%) within the core city area of Kathmandu Valley. Of the remaining portion of already cleared debris (average 0.44 million tons or 41%), based on the reuse/recycling rates of different building materials in the core city area, it was calculated that 0.60–0.69 million tons of building waste could be salvaged for reuse or recycling.

However, the reuse/recycling of building materials may not be achieved for reasons such as direct disposal without salvaging during the initial emergency period, the unavailability of storing locations for sorted materials, the low quality of materials in old structures, and changes in the structure type for new construction. Thus, the final destination for all of the already cleared building debris within the core city area of Kathmandu Valley was as follows: 0.63 million tons of deposited debris went to different deposition points and only 0.44 million tons of building debris were salvaged for reuse or recycling from 0.60–0.69 million tons of debris with the potential for reuse/recyclable quantity.

This study was mainly based on field-based case studies, and some limitations arose due to the short time frame and poor resource availability. Government and local authorities do not have any recorded information or quantitative data on debris generation and disposal. Quantification of debris disposal was performed only in major locations identified in reports submitted to the government; therefore, the disposal of debris waste through other channels or for use in land development areas could not be quantified. The reuse and recycling rate of materials from building debris varies significantly depending on the damage situation, area, and opinions of experts. This research requires further analysis of the reuse and recycling of materials from building debris and its potential for supplementing traditional building materials.

Furthermore, an evaluation of the environmental impacts related to random building debris disposal and potential improvements is required for future safe debris management.

3.4 Conclusions

Kathmandu Valley was severely affected by the Gorkha Earthquake in 2015, which claimed the lives of many people and damaged public, residential, and historic buildings. More than 85% of the buildings damaged were mud-bonded brick masonry buildings, some of which were made of adobe (sun-dried bricks), weak, and built with poor construction techniques resulting in the generation of large quantities of building debris after the earthquake. Building debris was not initially disposed of in the designated area proposed by the government and was instead disposed in vacant lands, low-lying areas, down the cliffs, land development areas, earthen roads, river banks (Kathmandu), and traditional ponds (Kirtipur) within 2–3 kms of the city; thus, municipalities did not face the problem of finding a large area (landfill) for the disposal of building debris. The reuse of materials such as brick, stone, wood, metal, and soil differed due to site conditions. Building material reuse was reduced in new constructions due to different types of structure or the poor quality of building materials. From the large amount of potential building debris generated in the core city area of Kathmandu Valley, one-third of the debris had already been managed two years after the earthquake; around 60% had been disposed on river banks, along the ring road, and in open spaces, while the remaining debris was salvaged for reuse or sold as important building materials for recycling. Nevertheless, two-thirds of the building debris still has not been cleared even two years after the earthquake.

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Chapter 4

Disaster Waste Management after the 2016 Kumamoto Earthquake: Experiences of Kumamoto and Comparison

4.1 Introduction

Disasters include adverse events resulting from earthquakes, tsunamis, typhoons, heavy rains, floods, volcanic eruptions, and fires. It is difficult to generalize about the disaster waste as there is a big difference in the nature of environmental impacts and types of waste generated from the individual disasters [1]. Although many published articles have discussed various aspects of the 2011 Tohoku Earthquake and tsunami, including the damages and disaster waste management in the affected areas [2][3][4][5][6], only one has described the 2016 Kumamoto Earthquake [7]. In addition, there has been no comprehensive report of official figures reported by the government on disaster waste generated by this earthquake.

4.1.1 Aim of the study

In this chapter, we report on the damages and disaster waste generated by the Kumamoto Earthquake and describes the waste management systems applied. Recycling is an important part of any disaster waste management system. Thus, we highlight examples from the Kumamoto case and other disasters of creating primary and secondary temporary waste storage sites and employing full-scale segregated recycling systems. We also present specific examples of cooperative networks among municipalities, which are shown to be critically important in dealing with disaster waste, and offer international examples. Finally, we offer suggestions about the future development of disaster waste management.

4.2 Damages and Disaster Waste Generated by the 2016 Kumamoto Earthquake

On 14 April 2016 at 9:26 pm, a strong earthquake (magnitude 6.5) occurred in the Kumamoto area, followed by a second one (magnitude 7.3) on 16 April at 1:25 am; hereafter, we refer to these as the “Kumamoto Earthquake.” Figure 4-1 shows the map of Kumamoto Prefecture and summarizes the damages caused by the earthquakes. As of 10 August 2017, 244 people had died and more than 170,000 houses and other buildings were affected by the earthquakes (8248 completely destroyed and 30,749 partially destroyed). Two recent earthquakes, the 2015 Gorkha Earthquake in Nepal and the 2008 Sichuan Earthquake in China, caused more casualties, but the direct economic losses varied greatly [8]. Direct economic losses at Kumamoto were estimated at USD22.4–43.0 billion (JPY 2.4–4.6 trillion yen) [7], whereas those in Nepal and China were USD7 billion [9] and USD 121 billion (RMB845.1 billion), respectively [10] [11].

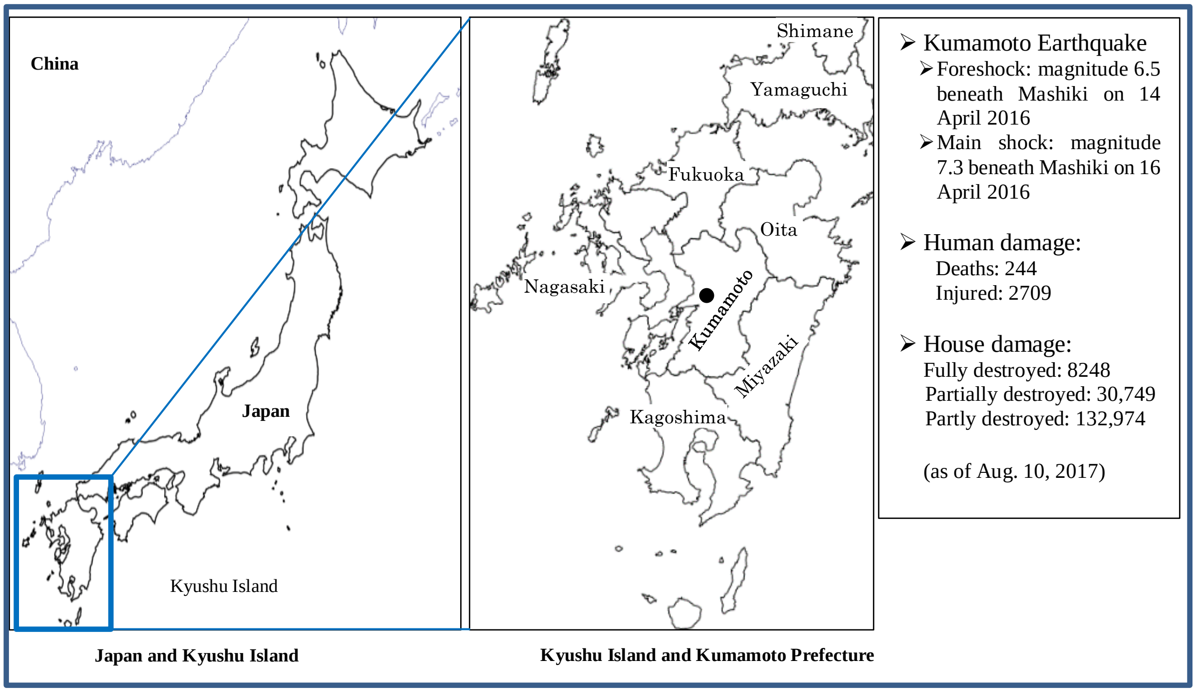


Figure 4-1: Kumamoto in Map and damages of Kumamoto Earthquake

As shown in Table 4-1, the estimated amount of disaster waste generated in Kumamoto Prefecture was 3.16 million tonnes (Mt). This volume was based on "the number of disaster damage certificates issued by the municipalities and the number of houses dismantled at public expense" multiplied by "the amount of disaster waste per house." The waste amount is small compared to that generated in the Great Hanshin-Awaji Earthquake (15 Mt) and the Great East Japan Earthquake (31 Mt). The volume is also smaller than that generated by recent earthquakes in other areas, for example, 20 Mt from the 2008 Sichuan Earthquake and 14 Mt from the 2015 Gorkha Earthquake [12] [13].

However, the volume of disaster waste was larger than that generated by other recent natural disasters in Japan (Table 4-1). The city of Kumamoto, the prefectural capital, was the worst hit area, generating about 1.48 Mt of disaster waste.

As a point of comparison, in 2015, Kumamoto city produced 0.236 Mt of domestic waste and 0.644 Mt of industrial waste, so the amount of disaster waste was equivalent to about 1.7 years annual of total waste. The Great East Japan Earthquake, only in the town of Ishinomaki among many towns and cities of highly affected three prefectures, generated 6.16 Mt of disaster waste, which is equivalent to the normal solid waste that would usually have been generated in 103 years [14].

Table 4-1: Disaster waste generated by major natural disasters in Japan

Disasters	Dates	Magnitude of Earthquake (in Richter Scale)	Volume of waste	House damage	Length of treatment
Great East Japan Earthquake	March 2011	9.0	31 Mt (including tsunami sediments of 11 Mt)	Fully destroyed：118,822 Partially destroyed：184,615	About 3years （not including the waste of Fukushima area）
Great Hanshin-Awaji Earthquake	January 1995	7.2	15 Mt	Fully destroyed：104,906 Partially destroyed：144,274 Partially damaged：390,506 Destroyed by fire：7,534	About 3 years
Kumamoto Earthquake	April 2016	6.5 and 7.3	3.16 Mt（estimate）	Fully destroyed：8,248 Partially destroyed：30,749 Partially damaged：132,974	About 2 years
Niigata-ken-Chuetsu Earthquake	October 2004	6.6	0.6 Mt	Fully destroyed：3,175 Partially destroyed：13,810 Partially damaged：103,854	About 3 years
Heavy Rain (landslide) Hiroshima city	August 2014	-	0.52 Mt	Fully destroyed：179 Partially destroyed：217 Partially damaged：189 Flood damage：4,164	About 1.5 years
Typhoon No.26 (landslide) Oshima, Tokyo Pref.	October 2013	-	0.23 Mt	Fully destroyed：50 Partially destroyed：26 Partially damaged：77	About 1 year
Kanto and Tohoku area (heavy rain and flood)	September 2015	-	0.05 Mt	Fully destroyed：53 Partially destroyed：5,054 Flood damage：3,220	About 1 year

(Source: Ministry of Environment Japan, 2018)

The most voluminous type of waste generated by the disaster was waste from the demolition, reconstruction, and rehabilitation of damaged buildings, but this waste has the potential to be a valuable resource [15]. After the disaster, poor sanitation condition in camps of disaster victims or support troops might result in serious public health problems like outbreak of cholera in Haiti after the 2010 Haiti earthquake [16].

To dispose of the disaster waste in Kumamoto, it is essential to use waste treatment facilities in the stricken areas. However, these facilities were also severely damaged by the earthquakes (Table 4-2), which caused heavy damage to waste incinerators, plants that convert waste into solid fuel (refuse-derived fuel), and human excreta (night soil) treatment plants. In addition, it took some time to repair some of the facilities.

Table 4-2: Damage to waste treatment facilities by the Kumamoto Earthquake

Organization	Facility	Type	Damage	Waste treatment conditions	Recovery period
Kumamoto City	Tobu Kankyo Kojo （Incinerator No.1）	Waste incineration	Operations stoped due to boiler damage	Began operation after Incinerator No.2 repaired, while IncineratorNo.1 was under repair. Some waste was partially treated at facility outside Kumamoto pref.	Incinerator No.2 : resumed operation on 1 May 2016 Incinerator No.1: resumed operation on 18 May 2016
Mifunekosasen Sanitation Facility Union	Mifunekosasen Clean Center （Incinerators No.1 & 2）	Waste incineration	Operations stopped due to partial destruction of facility	Waste was treated at facilities of the Uki wide-area Union Confederation and in Santo City.	Resumed operation on 21 July 2016
Mashiki, Kashima and Nishihara environment sanitation facility union	Mashiki Clean Center (Incinerators No.1 & 2）	Waste incineration	Operations stopped due to destruction of facility	Waste was treated at facilities of the Uki wide-area Union Confederation and Ariake wide area administration affairs union.	Resumed operation on 30 May 2016
Aso wide area civil service union	Aso Environment Center Miraikan （Incinerator No. 1 & 2）	Refuse Derived Fuel (RDF)	Operations stopped due to facility damage	Some waste was treated at facilities outside Kumamoto. Treatment at other facilities inside the prefecture is being considered.	Resumed operation on 1 August 2016

(Source: Ministry of Environment Japan, 2017)

In particular, the waste incinerator at Tobu Kankyo Kojo in Kumamoto city was severely damaged and required about a month to completely repair. Since the plant is the largest domestic waste incineration facility in Kumamoto Prefecture, its shutdown seriously affected the treatment of domestic and disaster waste; and required support and collaboration from a wide surrounding area to manage the waste. Even without the damages to incineration plants, cooperation between municipalities is necessary to deal with the large quantities of disaster waste, as seen with the treatment of debris from Miyako in Tokyo carried at a distance of 750 km, after the Great East Japan Earthquake [14].

4.3 Disaster Waste Management in Kumamoto

4.3.1 Disaster Waste Management Basic Flow and Treatment Flow Plan in Kumamoto

In the basic flow of disaster waste management in Kumamoto (as shown in Figure 4-2), it was found that disaster waste generated in the stricken area was treated and managed at different stages at various sites. Then, according to the types of waste and the extent of damage, the wastes were processed for reuse, recycling, incineration, or landfill. The disaster waste originates at the stricken area and was roughly classified at its origin and sent to the primary temporary waste storage site. When there are not enough classification facilities or primary storage sites have limited capacity, secondary storage sites are necessary. Selection of secondary storage sites is generally decided based on the scale of the disaster and the status of resource circulation in affected areas.

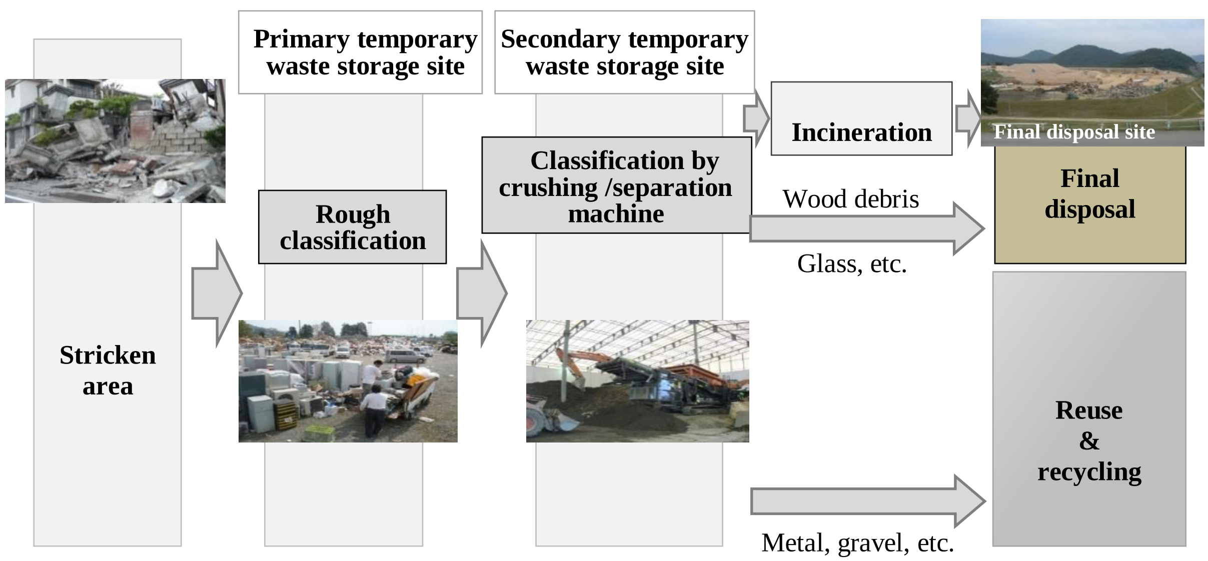


Figure 4-2: Basic flow of disaster waste treatment

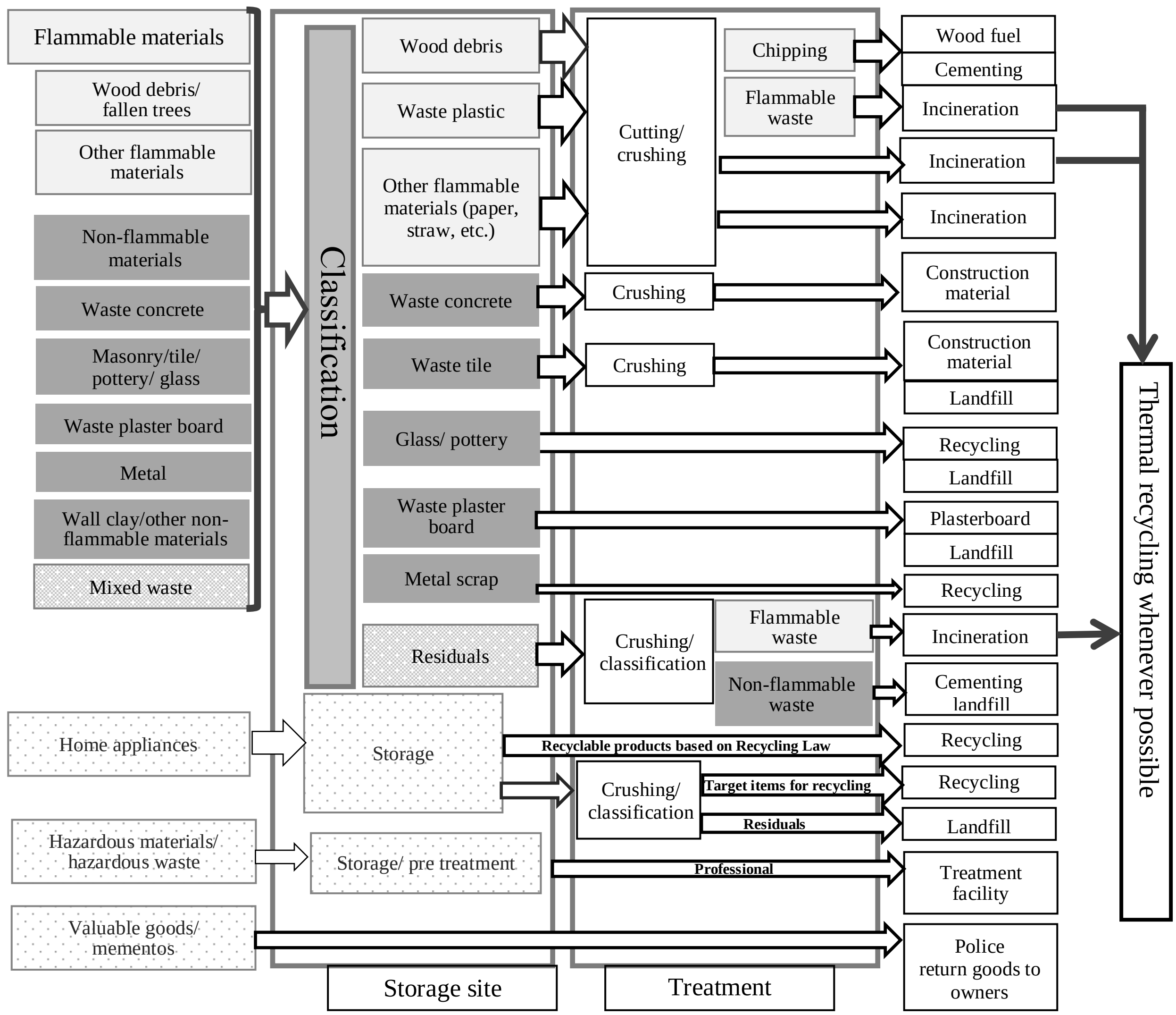
For the effective clearance of disaster debris, however, provision of abundant space for temporary storage and disposal is not always sufficient. In secondary temporary storage sites, roughly separated wastes were thoroughly separated and the reusable or recyclable materials like plastics, metals, gravels etc. were sent for reuse or recycling. Mixed wastes containing household goods, wooden materials, and large items were reduced in size by crushing and density separation of materials. Again, from the separation of mixed waste; materials like metals, plastics, gravels etc. were sent for reuse or recycling; materials like wood in the form of chips or the mixed glasses were sent for incineration. Energy recovery was done from the wooden waste however the glass was incinerated to reduce the hazard if it was deposited on land. Other inert materials, residue from the incineration plants were sent to landfill for the final disposal. In this basic flow of disaster waste in Kumamoto, wastes were treated and managed leaving less threat to the environment by treating all the waste in accordance to their type, maximizing reuse or recycling to reclaim the useful resources, energy recovery from the incinerated waste and very less final disposal quantity in landfill.

Geography & terrain, type of disaster and disaster community have strong and significant impact on system which is needed to give priority at planning of disaster waste management [17]. Coordination of efforts through the different stages of debris management is also important to avoid many of the environmental and psychological complications in the impacted area [18]. But in case of developing countries, awareness among community and political level plays a vital role while technical and financial capacities are the key requirements for successful recovery and utilization of disaster waste [19].

Many wooden houses were completely or partially destroyed by the Kumamoto Earthquake, leaving a large volume of wood debris in addition to non-combustible materials such as broken tiles and waste concrete from collapsed walls. Of the 1955 wooden buildings in the town of Mashiki, there was no seismic damage in 414 buildings; slight, small, and medium damage in 1014; large damage in 230; and total collapse in 297. Of the 297 collapsed wooden buildings, 214 were built before 1981, 76 were built from 1981 to 2000, and 7 were built after 2000 (National Institute for Land and Infrastructure Management, 2016 as cited in Takatani and Nishikawa, 2017)[20]. Kumamoto Prefecture used the Kumamoto Disaster Waste Treatment Flow Plan [21] classify waste by type to facilitate proper recycling and treatment of disaster waste. The separately collected waste are categorized broadly as organic waste, inorganic waste, mixed waste, home appliances, hazardous materials and valuable goods/mementos. The organic waste requires a special attention during storing as they are vulnerable for fire. Most of the wastes are in bulk form which requires crushing into small parts for treatment of the waste. Hazardous waste needs care and precautions while handling, storing and treatment. Figure 4-3 describes the Kumamoto Disaster Waste Treatment Flow Plan.

4.3.2 Temporary waste storage sites and disaster waste treatment in Kumamoto

Immediately after the earthquake, 54 primary waste storage sites were set up, with the number of sites eventually reaching 80. The cities of Kumamoto, Uki, and Uto used existing garbage collection points as primary waste storage sites. The cities introduced waste classification methods for storing classified items (e.g., flammable goods, home appliances, concrete). The methods were considered effective for reducing time and cost of waste treatment. As requested by seven cities (Uto, Minamiaso, Nishihara, Kashima, Kosa, Mashiki, and Mifune), Kumamoto Prefecture also established and ran secondary temporary waste storage sites in the Mashiki area. As the dismantling of houses and buildings progressed, the amount of disaster waste generated increased.



(Source: Ministry of Environment Japan, 2017)

Figure 4-3: Disaster Waste Management flow in Kumamoto

The affected areas were able to accelerate treatment of disaster waste by starting full operations at six secondary temporary waste storage sites in Kumamoto city by March 2017 (Table 4-3). These temporary waste storage sites in Kumamoto were categorized on the basis of type of waste stored as sorted debris/ dismantled debris storage site and dismantled debris storage site. There were six temporary waste storage sites in Kumamoto with storage area of 23.5 hectares hectares [22]. Kumamoto city is divided into East Ward, West Ward, Central Ward, North Ward and South Ward. Among five broad division of Kumamoto City, Toshima temporary waste storage center lies in East Ward; Kumamoto Port temporary waste storage center lies in West Ward; Senda Environmental Center and Hokubu temporary waste storage center lie in North Ward; and Jonan and Shinjonan temporary waste storage center lie in South Ward. Senda Environmental Center site is the largest temporary storage site in Kumamoto with storing area of 9.1 hectares.

Sorted debris/ dismantled debris were stored at Toshima and Jonan while only dismantled debris was stored at Shinjonan, Kumamoto Port, Senda Environmental Center and Hokubu.

Table 4-3: Secondary temporary waste storage sites in the city of Kumamoto [22]

Type of waste	Name of storage site	Area	Address
Sorted debris/ dismantled debris	Toshima	8.2ha	1489 Toshima-cho, Higashi-ku
	Jonan	0.5ha	34-1 Shimomiyaji, Jonan-machi, Minami-ku
Dismantled debris	Shinjonan	1.3ha	2127-2 Wanise Jonan-machi, Minamiku
	Kumamoto Port	2.4ha	1-4-1 Shinminato, Nishi-ku
	Senda Environ. Center	9.1ha	811 Kamao-machi, Kita-ku
	Hokubu	2.0ha	1046-2 Kusuno-machi,Kita-ku
Total		**23.5 ha**	

After the Great East Japan Earthquake, 215 temporary sites were set up in Iwate (68), Miyagi (116), and Fukushima (31) for the collection of the disaster waste [23]. In 1999 after the Marmara Earthquake in Turkey, demolition waste was disposed of in 17 dumpsites throughout the region, but there were also a number of illegal dumps [24].

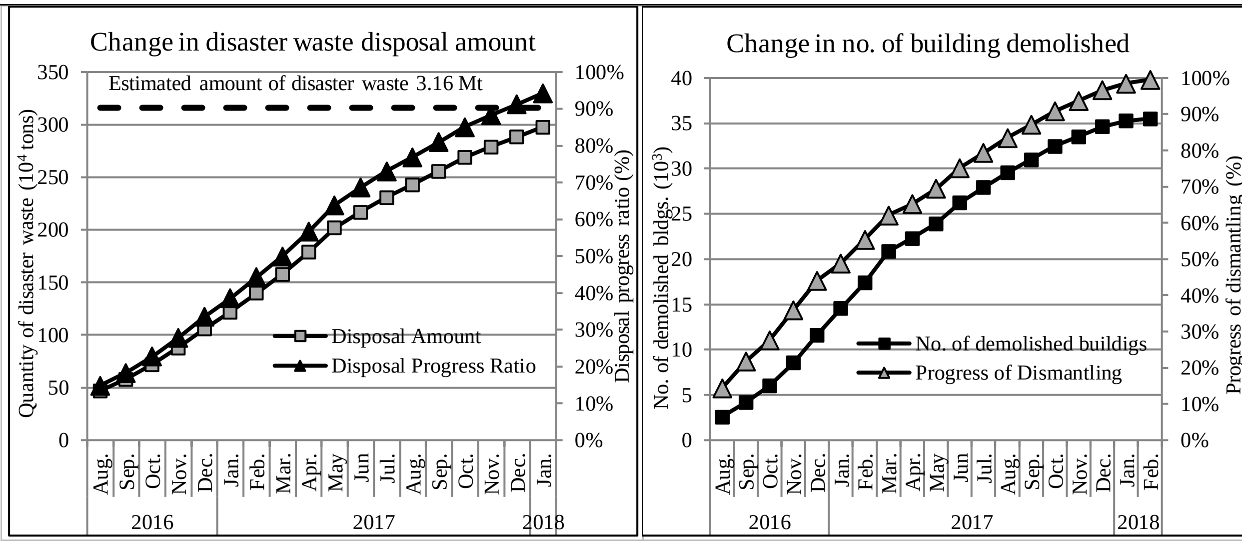
Kumamoto prefecture used about 9.8 hectares of land for secondary temporary waste storage site in order to help disaster waste treatment at primary waste storage sites run by seven cities/ municipalities. The volume of disaster waste treated at the secondary temporary storage site was around 0.2 million tons in total: 0.008 million tons of waste concrete, 0.028 million tons of roof tiles, 0.06 million tons of wood debris, 0.103 million tons of mixed waste, and 0.002 million tons of tatami and futon (Figure 4-4). Separation, crushing, and compression facilities were adopted for the disaster wastes in order to recycle them as much as possible and also reduce the volume of waste that goes to landfills (Figure 4-5). Waste concrete and tiles were reused mainly for building and civil engineering materials after removal of impurity materials. Wood debris were roughly crushed to reuse for cement raw materials making and for biomass power generation, and finely crushed to make raw materials for paper making. Mixed wastes generated from dismantled debris were classified by using equipment such as trommel to be used as fuel for cement raw materials and for incineration power generation. Inorganic materials and residues were disposed of at landfill sites. Waste tatamis and futons were treated by shredding and compression process for incineration energy recovery.

Figure 4-4: Disaster Waste Treated

Figure 4-5: Separation, crushing and compression facilities

In order to minimize environmental impacts, control measures were implemented in disaster waste treatment: for example, soundproof sheets and panels were used and water was sprinkled on debris during crushing/separation to control fly dust. To reduce the risk of fire at temporary storage sites, the following policies were established: (1) combustible mixed waste piles must not exceed 5 m in height (only combustible waste such an damaged wooden materials: less than 2 m), (2) the area per waste pile must be smaller than 200 m^2, and (3) the interval between piles be more than 2 m. In addition, as temporary waste storage sites close, a visual inspection must be done to check for contamination. Soil analyses are conducted and countermeasures are taken against soil contamination as needed. Twenty-eight municipalities were conducting disaster waste treatment as of July 2017. As of the end of January 2018, the amount of waste disposed exceeded 2,980,000 tonnes, with a 94.3% disposal progress rate (the amount disposed of relative to the estimated total amount of waste) and 76% recycling rate for treated waste (Figure 4-6).

For comparison, the recycling ratio in Iwate and Miyagi Prefectures for disaster waste generated after the Great East Japan Earthquake by the end of March 2014 was nearly 90% for both recycling and reuse [25]. The recycling ratio alone in Sendai 3 years after the disaster was 72% for debris and 96% for sediments, for an overall rate of 84% [26]. After the Great East Japan Earthquake, materials like wood were less recyclable than they would otherwise have been because of saltwater contamination; these materials needed to be stored or stacked by exposing them to rain to wash out salt until the salt levels decreased enough for recycling [27][14]. While incinerating the salt-water immersed wood under condition of low combustion temperature during the restoration efforts after the disaster, dioxins were likely to produce which are harmful to human health [28]. Dioxin is a group of chemical compounds that has strong toxic, carcinogenic and mutagenic effects that has been linked to immune suppression in humans [29]. The phenomenon of biodegradation by common white rot fungus for saltwater immersed wood was same as sound sap wood degradation [30]. However, it takes longer time to degrade in natural way, so an alternative method for treatment and disposal is necessary.



(1) Disaster waste treatment (as of the end of January 2018)

Estimated total waste amount (A)	Disposal amount (B)	(B=C+D) Recycled (C)	Disposal (D)	Recycling rate (C÷B) x 100	Disposal progress rate (B÷A) x 100
316×10^4 t	298×10^4 t	226×10^4 t	72×10^4 t	76%	94.3%

(2) Dismantling of collapsed houses through public financing (as of the end of February 2018)

Number of applications (A)	Number of dismantled houses (B)	Dismantling progress rate (B/A)
35,675	35,521	99.6%

Figure 4-6: The amount of treated disaster waste and the recycling, disposal, and dismantling rates, 2016 to 2018 (Adopted from MOE, Japan, 2018 [32] and modified)

Salvage operations after demolition of damaged buildings by Hurricane Katrina in New Orleans resulted in a total recovery rate of 48%, which varied from 28% to 62% of individual buildings by weight [31]. The "recycling ratio" in case of the Great East Japan Earthquake is the ratio of total waste reused and recycled to total waste generated. Denhart (2010) [31]used the term "recovery rate" in case of post-Katrina waste, for which case only the recycling of metals and concrete was possible because of a lack of recycling facilities for other materials. Denhart (2010)[31] also noted that all non-reusable materials were landfilled. Therefore, this "recovery rate" is the same as the "recycling ratio" in the case of the Great East Japan Earthquake.

According to Lauritzen (1998) [33], demolition and recycling technologies in most European countries are easy to implement and control, which has enhanced the economic feasibility of recycling in many European countries such that the recycling rate has reached 80% to 90% of construction and demolition waste. Post-disaster recycling of waste depends on many factors such as volume of waste, degree of mixing of waste, human and environmental health hazards, areal extent of waste, community priorities, funding mechanisms, time constraints, the recycling market, and existing and disaster-specific regulations [34].

4.4 Progress and Challenges of Disaster Waste Management in Kumamoto

4.4.1 Waste generated by household cleanup and building demolition

The types of waste generated by natural disasters will vary depending on the time and location of the disaster and the original form of the waste. Waste generated by the cleanup of furniture and other household items soon after a disaster and wastes discharged from evacuation centers have similar physicochemical properties as bulky waste and domestic waste produced in our daily lives. On the other hand, waste generated by the demolition of buildings has similar physicochemical properties as construction waste which is treated as industrial waste in normal times (i.e., concrete, timber and blocks). Table 4-4 shows that waste concrete accounts for about 30% of the total waste, combustible material about 15%, and mixed waste about 30%, 5 months after the Kumamoto Earthquake. However, after 6 more months, the rates had changed to more than 50% for waste concrete and 17% for waste wood, most of which was derived from the demolition of damaged structures.

The proportions of concrete in disaster waste of the Marmara Earthquake in Turkey in 1999 and Sichuan Earthquake in China in 2008 were greater than 50%, whereas the proportion was around 23% in the disaster waste caused by the Indian Ocean tsunami in Sri Lanka in 2004. Unlike in Japan, the waste composition included large amounts of masonry (bricks, stones, and “cabok” [lightweight red laterite] in Sri Lanka), which accounted for about 25%, 40%, and 59% of the disaster waste in Turkey, China, and Sri Lanka, respectively [24][35][10]. The proportion of concrete in disaster waste was higher in Japan than in these countries (developing countries). The disaster waste generated by the Great East Japan Earthquake and the induced tsunami included waste such as damaged ships, fishing nets, and tsunami sediment, so the composition was different as compared to the disaster waste generated in the Kumamoto Earthquake [14].

After the Great East Japan Earthquake in 2011, Japan experienced not only the Kumamoto Earthquake but also other disasters such as the Izu-Oshima Heavy Rainfall, Hiroshima Landslide, and Kanto-Tohoku Heavy Rainfall. Even so, only 43% of prefectures and 21% of municipalities had created their own disaster waste treatment plans as of March 2016. Cities that have had existing disaster waste management plans and a manual on how to manage and treat disaster waste have succeeded in responding to disaster waste. Higashi-Matsuyama and Asakura Cities have smoothly set up primary storage sites and have recycled valuable materials. A waste treatment plan must consider the nature of disaster wastes, whose physicochemical properties can change significantly based on the time of the disaster occurrence and the cleanup methods. First, it is necessary to set up appropriate waste storage sites. For primary storage sites, it is important to consider that much of the mixed waste generated by the cleanup of houses and buildings is collected just after a disaster. At this stage, volunteer activities by citizens play crucial roles because separation might become difficult if they mixed up disaster waste at the sources in emergency and early response phases.

Table 4-4: Amount of disaster waste generated classified by material type (as of 14 Dec. 2017)

Waste Source	Activity duration,quantity and proportion of disaster waste	Waste disposal amount/ estimated waste generation amount	Waste concrete	Waste wood	Waste metal	Remaining materials			
						Mixed waste (landfill)	Combustible material	Tile	Other
Waste generated mainly by household cleanup	April-August 2016 disposal amount (thousand t)	471	137	45	4	153	68	45	18
	Proportion (%)	100.0	29.1	9.6	0.9	32.4	14.5	9.6	3.8
Waste generated mainly by building demolition	September 2016 - March 2018 Estimated generation amount (thousand t)	2,422	1,233	411	9	263	63	252	190
	Proportion (%)	100	50.9	17.0	0.4	10.9	2.6	10.4	7.9
	Total (thousand t)	**2,893**	**1,371**	**456**	**14**	**416**	**131**	**297**	**208**
	Proportion (%)	**100%**	**47.4**	**15.7**	**0.5**	**14.4**	**4.5**	**10.3**	**7.2**

Note: Some totals do not match because of rounding.

Additional key point for disaster waste treatment is to set up secondary waste storage sites and the classification of wastes from dismantled houses and buildings. During this stage, it is important to create basic rules and schemes for waste classification. In 2000, the Construction Material Recycling Law was enacted in Japan, aimed at the recycling and reuse of waste construction materials. The law requires builders to sort and recycle specific construction materials (e.g., concrete, asphalt, waste wood, and construction sludge) generated in some large-scale demolition work, even after disasters. In some cases where saving lives and eliminating road obstacles are priorities, it might be difficult to dismantle and sort some of the construction materials. However, even during and after disasters, it is necessary to classify and dismantle construction materials based on sophisticated recycling technologies and the regulations created by the Construction Material Recycling law. In March 2018, the Ministry of Land, Infrastructure, Transport and Tourism and the Ministry of the Environment jointly issued the document, “Points to Consider for the Recycling of Construction Materials in a Disaster.” It recommends that municipalities provide information on how to classify/demolish construction materials, sign cooperation agreements with relevant businesses before demolition work begins, make arrangements for setting temporary waste storage sites, and establish a waste treatment flow. Due to no pre-established C&D waste management plan prior to the disaster in 2011 Canterbury earthquake, New Zealand a number of inefficiencies resulted in delayed cleanup and whole recovery process. The strategy “pick and go” had speeded up the cleanup work however problems like lack of sufficient temporary storage sites, increased processing cost due to non-separation of debris which lead to more waste in the landfill [36].

4.4.2 Experiences of recycling and treatment of disaster waste in Kumamoto

To reduce and recycle Kumamoto’s disaster waste, it was processed at the classification stage by crushing and separation machines with a target-recycling rate of over 70%. Efforts were coordinated among governmental and private sectors concerned about using the recycled materials at local factories and for public works. Even after all recycling efforts, a large amount of waste remained. In this case, incineration and thermal recycling were employed whenever possible. Kumamoto Prefecture has 21 incineration facilities (treatment capacity: 2204 t/day) for domestic waste. However, as shown in Table 4-2, some of the facilities were seriously damaged by the earthquake. In addition, some facilities needed normal periodic repair. These conditions made it difficult to treat disaster waste only within the prefecture. Municipal and prefectural officials therefore decided to move some operations outside the prefecture, including separation of mixed waste, recycling of waste wood, and incineration of combustible waste. It was found that more temporary incinerators could improve the efficiency of waste treatment, compared to area-wide management which increases the average cost. But the temporary incinerator facilities were not easy to build in a short period, however the area-wide management of disaster waste was still useful for the disaster-hit municipalities which shortens the disposal periods [4]. Thanks to arrangements by the Ministry of the Environment and Disaster waste treatment network (D.Waste-Net), disaster waste was treated by municipalities and private-sector entities across the country. Waste treatment business operators in Kumamoto also outsourced disaster waste treatment to waste management businesses and cement companies outside the prefecture.

The disaster waste treatment option should consider environmental and engineering risk along with cost. Also, quantification of health and environmental effects of burning of different types of disaster waste is also a necessity in case of open burning [37]. Healthcare waste management after the disaster is a serious issue after the disaster for probable spread of epidemics which are more critical in case of developing countries. After the two consecutive disasters, earthquake and cholera outbreak in Haiti in 2010, generation of the healthcare waste did not peak instantly but increased gradually. Practice of smoky open burning of healthcare waste in Haiti during disasters increased both health and environmental risks which seriously appeal for all stakeholders to create awareness, training to the staffs, strengthen the guidelines and assist in acquiring effective technologies and infrastructures [38]. It was found that all the primary storage sites after a month of piling debris were at low risk of fire as the internal temperatures of the combustible waste were equal or less than the outside temperature [39]. It is very important from the safety point of view to prevent the combustible mixed waste with increased concentration of saturated fatty acid, as fire occurs from the spontaneous ignition caused by the heat from fermentation of wooden matter of disaster waste. More than 40 such fires occurred in Tohoku region after 2011 Great East Japan Earthquake [40][41]. In addition, because of the damage to the Fukushima nuclear plant, materials for recycling also had to be monitored for potential radioactivity [14], as it was found that the residue of incinerated waste around Fukushima resulted in higher level of radioactivity (associated with radiocesium) [42]. Soil contaminated with the tsunami related deposits mainly contained gypsum-based deposit, lime-based deposits and naturally occurring heavy metals need to be treated properly with appropriate techniques for separating the contaminants or, immobilizing the heavy metals to preserve the living environment and improving public health [43][44]. The rotatory crushing and mixing method (RCM) can be applied for the separation, crushing and removal of disaster waste and restoration of the farmland with soil [45].

Natural disasters generate large amounts of all kinds of flammable and non-flammable materials and products from houses and buildings, including waste soil and stones. Immediately after a disaster, sufficient caution is needed in the treatment of waste electric appliances and household items containing asbestos. Items containing asbestos should be properly disposed of based on the “Handling Manual Concerning Prevention of Asbestos Emission at the Time of Disaster” [46]. For the L’Aquila Earthquake (2009) and the Emilia Earthquake (2012) in Italy, 2400 tonnes and 11,000 tonnes, of debris respectively mixed with asbestos have been managed [47]. For the effective management of asbestos remained in built-in environment that comes after demolition can be estimated from the stock and flow model as described in Donovan et al., 2016 [48] which after approaching the problems from the stocks, provides the method for projecting future waste management requirements. Kumamoto Prefecture has numerous solar power plants, including mega solar plants. These solar panels and facilities were also damaged by the earthquakes, and the prefecture was faced with the task of repairing the damaged plants and recycle the destroyed items. Very careful treatment is required in handling the solar modules at solar power plants, which mainly consist of glass and produced power which may cause electric shock if the electric paths in the circuit are obstructed. In April 2016, the Ministry of the Environment published “Guidelines for Promoting Recycling of Solar Panels” [49].

4.4.3 Networks and cooperation among municipalities and other organizations

4.4.3.1 Support from municipalities and organizations for disaster waste management of Kumamoto

After 2011 Great East Japan Earthquake, disaster waste by the local government and residents outside the affected area was difficult to accept due to the public concern of health as the disaster waste contained various substances including hazardous materials in spite of existence of the associations for regional affairs (*Ichibu-jimu-kumiai*) and the request made by Ministry of Environment, Japan to accept the disaster waste. Later, the disaster waste was accepted by the neighboring municipalities which may be due to financial support from central government and the next may be the solidarity (Kizuna in Japanese; means "bonds of emotion") for the disaster victims after the earthquake [50]. Many municipalities provided garbage trucks and sent staff to stricken areas to collect domestic waste and other debris (Table 4-5).

The cities of Kumamoto and Mashiki-cho received support from 21 April to 1 July and from 20 April to 11 July, respectively. The Japan Waste Management Association called for support from municipalities across the country and coordinated disaster waste treatment assistance. Some municipalities helped Kumamoto based on prior mutual assistance agreements. Iwate, Miyagi, and Sendai sent staff who were experienced in the disposal of disaster waste generated from the Great East Japan Earthquake of 2011 to help draw up plans for Kumamoto.

Different cities in Kumamoto Prefecture received support from municipalities and different organizations for Kumamoto disaster waste management. Kumamoto city received waste collection support from garbage trucks from 57 cities and associations. Main cities supporting Kumamoto city for waste collection by garbage collection were Shizuoka, Nagoya, Kyoto, Gifu, Yokkaichi, Kobe, Sakai, Osaka, Higashi Osaka, Fukuoka, Kita Kyushu, Nagasaki etc. In addition, the municipal solid waste generated in Kumamoto city was treated in wide areas outside the Kumamoto, including in Fukuoka, Kita Kyushu, Saga, Sasebo, Omura, Nagasaki, by 20 cities and associations. For Kumamoto city, experienced staffs in management of disaster waste were supported by Sendai city.

Waste collection in Mashiki-machi, which is a smaller town compared with Kumamoto City, was supported by 10 cities with garbage trucks. Main cities supporting in waste collection included Yokohama, Nigata, Kobe, Sagamihara, Hamamatsu. Staffs who were experienced in disaster waste management was supported by Union of Kansai Governments Wakayama, Sendai city and Hamamatsu city for Mashiki-machi.

Table 4-5: Support from municipalities and organizations for Kumamoto disaster waste management

Stricken areas	Support for waste collection by garbage trucks	Treatment of municipal solid waste in wide areas outside Kumamoto	Dispatch of staff
Kumamoto city	Shizuoka; Nagoya; Kyoto; Gifu; Yokkaichi; Kobe; Sakai; Osaka; Higashi Osaka; Fukuoka; Kita Kyushu; Nagasaki; etc. **(Total: 57 cities and associations)**	Fukuoka, Kita-Kyushu, Saga, Sasebo, Omura, Nagasaki, etc. **(Total: 20 cities and associations)**	Sendai city
Mashiki-machi	Yokohama; Nigata; Kobe; Sagamihara; Hamamatsu; etc. **(Total: 10 cities)**	—	Union of Kansai Governments Wakayama, Sendai city, Hamamatsu city.
Yashiro-shi	Omuta and Arao integrated administration	Omuta and Arao integrated administration	—
Aso integrated administration of a large regional office work association	Oita city	Oita city	—
Kikuchi Kankyo	Kagoshima city, Kurume city, Tsukushino-Ogoori-Kiyama integrated administration	Kagoshima city, Kurume city, Tsukushino-Ogoori-Kiyama integrated administration	—
Yufu city	Oita city	Oita city	—

(Source: Ministry of Environment Japan, 2017)

Yashiro city received support from the integrated administration of Omuta and Arao; the integrated administration of Aso, consisting of a large regional office work association, received support from Oita city; Kikuchi Kankyo received support from Kagoshima city, Kurume city, and the integrated administration of Tsukushino, Ogoori, and Kiyama; and Yufu city received support from Oita city.

The city collected household waste after the earthquake at existing waste collection points. Of the 20,000 existing stations, 10,000 were in stricken areas. Some stations initially experienced difficulties; for example, people discharged disaster waste mixed with domestic waste or collectors forgot to collect waste. To solve such problems, Kumamoto conducted intensive collection of waste, both the usual combustible waste and disaster waste, from 16 April to 3 June with the support of other municipalities and from 21 April with the support of businesses.

4.4.3.2 Disaster waste treatment network (D.Waste-Net)

Many municipalities and organizations helped support Kumamoto Prefecture deal with disaster waste. Disaster waste treatment network (D.Waste-Net), promoted by the Ministry of the Environment (MOE), provided assistance in these efforts (Figure 4-7).

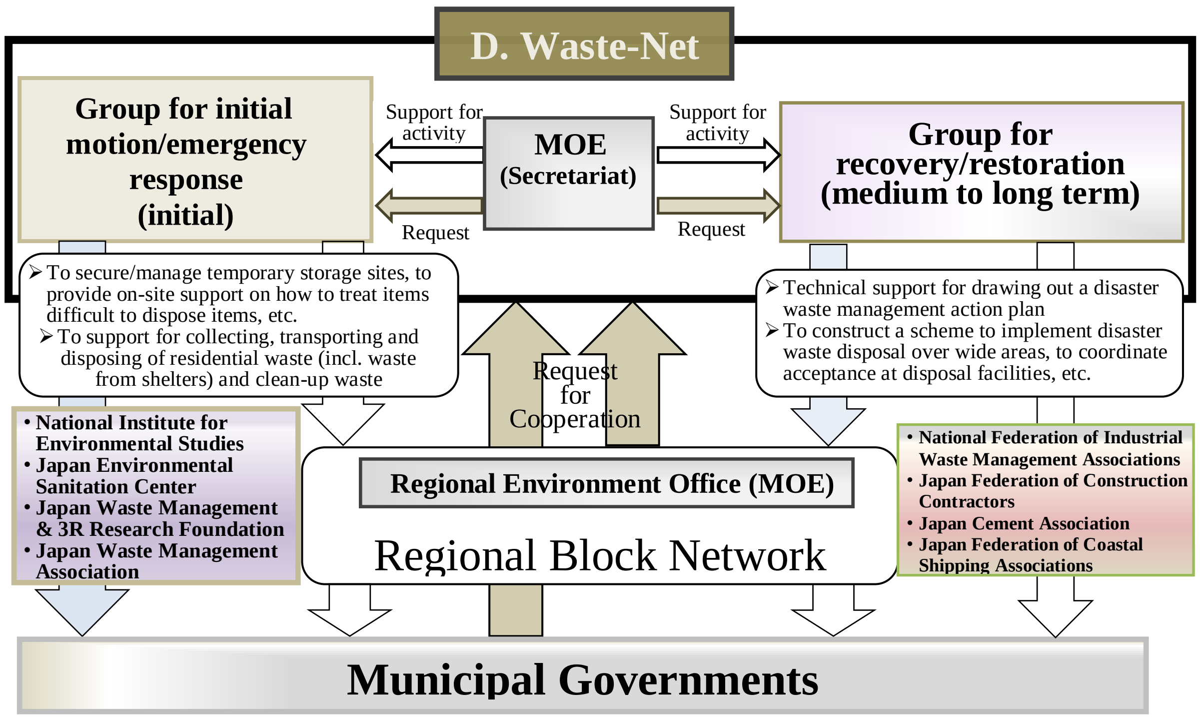


Figure 4-7: Disaster waste treatment network

(Source: Ministry of Environment Japan, 2018)

Disaster waste treatment network (D. Waste-Net) was established in 16 September 2016 to support the disaster affected area to deal with disaster waste issues. It is a network of groups coordinated under the Ministry of Environment (MOE), Japan Secretariat with the group for initial motion/emergency response and group for recovery/restoration in the central level. The Regional Environmental Office (MOE) with other agencies and organization lies in Regional block network in the middle to support the Municipal Governments.

Local Government or Municipal governments are at the target level to receive the support in this network. Different academic and research institutions, waste management associations and federations are supporting the municipal governments under the D. Waste-Net with emergency response groups or recovery/restoration groups. After the disaster event occurs, Municipal Governments and Regional

Environment Office request for the cooperation and support to MOE. The MOE requests both groups, Group for initial motion/emergency response and Group for recovery/restoration in D. Waste-Net in the central level with provision of support for the activities to activate their task in the disaster affected area.Group for initial motion/emergency response activates its work in initial stage immediately after the disaster event. Their main task is a.) To secure/manage temporary storage sites, on-site support on how to treat items difficult to dispose of, etc. and b.) To provide support for collecting, transporting and disposing of residential waste (including waste from shelters) and clean-up waste. For these activities, the group supports the Municipal Governments directly or through the Regional Environment Office to Municipal Governments. The group is again supported by the research institutions, associations or federations like National Institute for Environmental Studies, Japan Environmental Sanitation Center, Japan Waste Research Foundation, Japan Waste Management Association etc. are supporting the initial emergency response group with their expertise.

Similarly, Group for recovery/restoration will start its work after the initial emergency response was completed and it works for medium to long term. Their main task is for a.) Technical support for drawing out a disaster waste management action plan, and b.) To construct a scheme to implement disaster waste disposal over wide areas, to coordinate acceptance at disposal facilities, etc. The group supports the Municipal Governments directly or through the Regional Environment Office to Municipal Governments in implementing these activities. This group is supported by associations and federations like National Federation of Industrial Waste Management Associations, Japan Federation of Construction Contractors, Japan Cement Association, Japan Federation of Coastal Shipping Associations etc.

4.4.3.3 D.Waste-Net support activities in disaster waste management of Kumamoto

On 16 April 2016, the staffs of MOE, the Regional Environmental Office, D.Waste-Net, and Kumamoto Prefecture visited waste storage sites in the affected areas, evaluated conditions, and provided advice to relevant stakeholders in the stricken areas. For example, D.Waste-Net staff gave advice on how to separate and store cleaned-up waste at primary waste storage sites; Table 4-6 shows more of the support actions taken by D.Waste-Net. It was seen that sixteen organizations were involved in supporting the affected area based on their expertise and resources availability through D.Waste-Net. Support for the affected area by different organizations were; Association for Electric and Home Appliance supported the set up of contact lines for home appliance disposal while PC3R Promotion Association supported the setting up of contact lines of personal computers. National Institute for Environmental Studies dispatched support teams to teach the disaster waste treatment whereas Japan Environmental Sanitation Center dispatched support teams to provide technical help on waste disposal and sanitary measures.

Table 4-6: D.Waste-Net Support Activities

Organization	Support
Association for Electric Home Appliances	**Set up contact lines for home appliance disposal**
National Institute for Environment Studies	**Dispatch support teams to teach how to treat disaster waste**
Japan Cement Association	**Produce a guideline for waste treatment at cement factories Provide information to member companies**
Zenkoku Kankyo Seibi Kyodo Kumiai Rengokai (Kanseiren)	**Provide equipment for excreta treatment**
Japan Demolition Contractors Association	**Adjust support systems from other prefectures**
Zenkoku Seisou Jigyo Rengokai (Zenseiren)	**Dispatch garbage trucks and staff Create a support team from outside the prefecture (Hiroshima, Fukuoka, etc.)**
Japan Waste Management Association	**Adjust expanded support for Kumamoto city and Mashiki city**
Japan Association on Odor Environment	**Advise on sanitation measures**
Japan Freight Railway Company	**Prepare disaster waste transport containers Provide technical advice for municipalities on container transportation**
Japan Environmental Sanitation Center	**Dispatch support teams to provide technical helps on waste disposal and sanitary measures**
Japan Association of Environment Preservation	**Provide equipment for municipal solid waste and excreta treatment**
Japan Disaster Treatment Systems	**Treatment of disaster waste in wide areas by member enterprises Support for running secondary temporary waste storage sites**
Japan Pest Control Association	**Advise on sanitation measures**
Japan Society of Material Cycles & Waste Management	**Patrol temporary storage sites and give technical advice Survey disaster waste unit generation rate**
Japan Waste Research Foundation	**Survey coverage of disaster waste and actual damage to buildings and houses**
PC3R Promotion Association	**Set up contact lines for recycling of personal computers**

(Source: Ministry of Environment Japan, 2017)

Zenkoku Kankyo Seibi Kyodo Kumai Rengokai (Kansairen) and Japan Association of Environment Preservation provided equipment for excreta treatment, additionally Japan Association of Environment Preservation provided equipment for municipal solid waste treatment as well. Japan Demolition Contractors Association adjusted support system from other prefectures in the affected area and Japan Waste Research Foundation assisted in survey coverage of disaster waste and actual damage to building and houses. Japan Association on Odor Environment and Japan Pest Control Association supported by advising on sanitation measures. Japan Waste Management Association adjusted expanded support for Kumamoto city and Mashiki city. Japan Freight Railway Company prepared disaster waste treatment containers and provided technical advice for municipalities on container transportation. Japan Disaster Treatment System supported in treatment of disaster waste in wide areas by member enterprises and for running secondary temporary waste storage sites. Japan Society of Material Cycles and Waste Management supported in patrolling temporary storage sites and give technical advice; and survey disaster waste unit generation rate. Japan Cement Association produced a guideline for the waste treatment at cement factories and provides information to the member companies. Zenkoku Seisou Jigyo Rengokai (Zenseiren) dispatched garbage trucks and staffs and also created a support team from outside the prefecture (Hiroshima, Fukuoka etc.).

It is also important that the national and municipal governments should improve a public trust on them by additional communication about risks, benefits and costs associated with hosting disaster debris [50][51]. In the case of the Gorkha Earthquake in Nepal, the Ministry of Home Affairs took the lead for the management of disaster waste and relief and rescue activities and coordinated with volunteers of different NGOs and other rescue organizations from different countries. Nepal's army and police force took part in the demolition of damaged vulnerable buildings. The United Nations Development Program (UNDP) and international organizations such as, Oxfam, International Organization for Migration (IOM), CARE, and many other support organizations provided technical assistance and funds for the safe demolition and disposal of building debris [9].

After Hurricane Katrina in 2005 in the United States, state, county, and local municipalities had jurisdiction with regard to the cleanup, but federal agencies such as the Army Corps of Engineers, the U.S. Coast Guard, and the Environmental Protection Agency coordinated cleanup assistance efforts. In general, the Federal Emergency Management Agency (FEMA) receives funding from the Disaster Relief Fund and provides support in planning, supporting, providing resources, implementing programs, and providing emergency services to state, local, and tribal governments [52]. Developing nations generally need more support in emergency rescue and relief, including cleanup work, in terms of funds, logistics, and technical expertise from developed countries and international organizations, whereas developed nations can generally manage with less support from other countries. Among different stakeholders involved in waste management activities, NGOs and civil society organizations' contribution in case of developing countries have been effective in improving waste management services though waste management was a governmental function. Involvement of NGO resulted in 87% of community participation level for source separated collection in Raj Bhavan ward of Puducherry city in India [53]. Similarly, in case of developing countries, partnerships building in collaborative effort of organizations like World Wildlife Fund and the network organization *access2innovation* were successful by mobilizing the stakeholders around in improving waste management system in Kasese District of Uganda [54].

4.4.4 Dismantling of collapsed houses with public finance

Public finance was used to fund the dismantling of houses that were declared at least 50% damaged after the Kumamoto Earthquake; it was also used after the Great Hanshin-Awaji Earthquake and the Great East Japan Earthquake. This system allows municipalities to dismantle and remove collapsed houses for the owners with the aid of public financing. After normal disasters, damaged houses judged as “less than half destroyed” are regarded as the owners’ responsibilities and are not razed with public financing. Because the Kumamoto area was hit twice by approximately magnitude 7 earthquakes that caused great damage to residences, the volume of waste generated in the process of dismantling and removing collapsed houses was huge. Helping remove the damaged houses is a good example how financial aid can help during large-scale disasters.

But in case of 2010-2011 Canterbury earthquakes in New Zealand, uncertainties arose in the recovery works by having significant effect on post-earthquake decision-making strategies for the building owners due to insurance structure in New Zealand and lack of clarity in building regulations for building demolition [55]. No public funds were used to demolish buildings after the 2015 earthquake in Nepal. Demolition and removal of debris from private buildings was the responsibility of owners who had to pay for skilled workers or for machines to remove vulnerable buildings according to government regulations [56]. Many international organizations supported local residents, however, especially outside the core of Kathmandu with “cash for work” programs that paid families to demolish and remove the debris to support their livelihood during this emergency period [57]. A similar cash for work model was adopted in the demolition and debris removal of damaged buildings in Haiti after the earthquake in 2010 [58]. Case study on pre-disaster management by the local governments are essential for different type of disaster, their scales and the maximum damages can provide information on potential debris that can be generated, debris removal plans, open spaces required for temporary storage, transportation networks and management options can be planned in advance [59] [60]. The framework for debris management system as suggested by [61] and [62] can be useful for the decision makers to know the necessary budget and time for debris removal in timely manner by incorporating the data of past debris removal in the proposed framework and compare the difference between actual and estimated cost from the system with enhancement of its resiliency to evaluate an existing system under different disaster scenarios. Another framework of estimation for building information modeling (BIM) for demolition waste can be useful in the estimation of demolition waste produced at the demolition stage along with tools to calculate the disposal charges, pick-up truck estimations, recycling practices and environmental impact assessment after inclusion of adjustment factors in the framework [63]. All areas in Japan should conduct disaster contingency planning so that they are better prepared when disaster strikes.

4.5 Findings and discussion

From the study in this chapter, it was found that 3.16 million tons of disaster waste was estimated to be generated in Kumamoto Prefecture from the Kumamoto earthquake 2016 of which Kumamoto City alone generated 0.88 million tons which was equivalent to 1.7 years of domestic waste generated. The treatment facilities for the domestic waste were damaged in the earthquake-stricken area which required sometime to repair some of the facilities whereas it some severely damaged facilities required longer time to be repaired. In those case, disaster waste was treated in other area with the support and collaboration within wide surrounding area in neighboring municipalities. The study also revealed that the quantity of waste generated with a single disaster event can overwhelm the existing waste management system.

However, planning for the disaster waste prior to the disaster event can be helpful for the management aspect in terms of handling, sorting, storing, treating and final disposal of the disaster waste. Thus, Kumamoto followed the basic flow for disaster waste management where the mixed waste and debris were roughly separated in origin by the voluntary involvement of the citizen and sent to the temporary storage sites. Sorting the waste in the origin is helpful in handling the different type of waste and treat the particular waste type so that increases the recycling of materials and leaving very less disposal. In fact, it will lead to reduce the time and cost for effective management of disaster waste.

For the initial clearance of the disaster waste and opening of the roads, the disaster waste should be stored temporarily. It was found that there were 54 primary temporary storage sites established with maximum of 84 in peak time in Kumamoto Prefecture and 6 secondary temporary storage sites were established in Kumamoto City only. Provision of abundant open space inside or near the city area are useful in many aspects in the planning of urban area and those area can used as the temporary storage sites for the debris. Governments should not feel difficulty for finding the temporary storage area after the disaster had occurred.

In Kumamoto, the basic flow of waste treatment, the mixed debris were roughly separated and send to the secondary temporary storage sites where the waste were thoroughly separated and send for reusing and recycling; mixed waste were reduced in size and separated by density separation method and send for reuse and recycling. The classification of the waste was done on the basis of its properties as organic, inorganic, mixed, home appliances, hazardous and valuable goods/mementos which requires specific treatment option and close monitoring to avoid possible hazards like fire for flammable goods and special handling for the hazardous waste. These all efforts were for the effective management so as to reduce the environmental threats, maximize the reuse or recycling to reclaim useful resources, recover energy from the incinerated waste and minimize the final landfill amount. It was found that 2.98 million tons of disaster waste has been managed by the end of January 2018 with recycling rate of 76% and disposal progress rate of 94.3%. Also, the dismantling progress rate of the public building using the public fund was 99.6% by the end of February 2018.

It was found that D.Waste-Net formed the strong network among the different organizations within the country of Japan to support after the disaster event for the treatment and effective management of disaster waste in terms of skill, expertise and resource to deal with large amount of disaster waste in the short period.

The findings from the Kumamoto disaster waste management suggest to have comprehensive planning about the disaster waste management in advance with abundant open space in the settlement area for the future temporary storage sites. The proper planning and guidelines on the waste management and disaster waste with efficient facilities of waste handling, treatment and disposal should be effective with strict implementation. The single effort of the government is not always helpful in management of waste and waste management is basically a discipline act that each citizen should take part in its effective management. The guidelines and technologies effective in case of Kumamoto might not be applicable in all part of the world as the type and amount of waste generation is strictly based on the type/nature of the disaster, locality and the type of infrastructures. Thus, the country or local government should have their own waste management plan and guidelines for both domestic and disaster waste that is suitable for their own place and the type of waste generation. Beyond these, voluntary support of the residents and the network and cooperation among the various organization in Japan had showed additional important factor among many others to deal with disaster waste leading to achieve the desired recycling and disposal rates.

4.6 Conclusion

It is generally recognized that Japan must prepare for an earthquake in the Nankai Trough and a potentially massive earthquake striking the Tokyo metropolitan area. The disaster scales are predicted to be much larger than that of the Great East Japan Earthquake. In addition to these large earthquakes, large-scale typhoons and flooding are predicted to increase because of climate change. Implementing measures for handling disaster waste is one of the key points for material cycle and waste management. Thanks to the tremendous efforts by many people in the stricken areas of the Kumamoto Earthquake, it is likely that treatment of the disaster waste will be accomplished within the target period of 2 years. Knowledge gained through experience with disasters such as the Kumamoto Earthquake should help us to prepare for future disasters, especially following points; 1) management of huge amount of destroyed houses and buildings, 2) establishment of treatment flow beyond the affected region, 3) effective support and receiving the support, 4) integration and/or standardization of the separation. Supports during the disaster are in terms of skill, expertise and logistics provided to the affected areas which need to be managed properly for the effective outcomes. Similarly, integration of different disaster waste separation is essential for the quality of recycled materials to maintain the uniform standard.

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Chapter 5

Conclusions and recommendation for future research

5.1 Conclusions

From the study on characterization and management of disaster waste, the conclusions of the study can be concluded in the following.

The unit generation rates were different for buildings with differing structural types or number of stories. The building waste generated from the buildings in Nepal ranges from 1.90 to 3.23 tons/m^2 debris, of which masonry and concrete make up the majority for all type of buildings. The unit generation rates by weight were higher in Nepal than they were for similar buildings in China and Japan. Unit generation rates depend upon the method of estimation i.e. material stock estimation and post-disaster field estimation. Unit generation rates for the public RC type building in Nepal and Japan excluding the foundation materials were close to the similar building in China. Similarly, the unit generation rates for wooden buildings in Japan were nearly equal using different estimation methods. The unit generation rate in volume was higher in Japan than it was in Nepal and Sri Lanka.

The field studies on the disaster waste management and disposal status of debris were made after the Gorkha earthquake in Kathmandu Valley of Nepal. Kathmandu Valley was severely affected by the Gorkha Earthquake in 2015, which claimed the lives of many people and damaged public, residential, and historic buildings. More than 85% of the buildings damaged were mud-bonded brick masonry buildings, some of which were made of adobe (sun-dried bricks), weak, and built with poor construction techniques resulting in the generation of large quantities of building debris after the earthquake. Building debris was not initially disposed of in the designated area proposed by the government and was instead disposed in vacant lands, low-lying areas, down the cliffs, land development areas, earthen roads, river banks (Kathmandu), and traditional ponds (Kirtipur) within 2–3 kms of the city; thus, municipalities did not face the problem of finding a large area (landfill) for the disposal of building debris. The reuse of materials such as brick, stone, wood, metal, and soil differed due to site conditions. Building material reuse was reduced in new constructions due to different types of structure or the poor quality of building materials. The amount of potential building debris generated in the core Kathmandu Valley area was 3.23 million tons, of which 1.07 million tons were already managed two years after the earthquake through disposing 0.63 million tons on river banks, along the ring road, and in open spaces. The remaining debris was salvaged for reuse or sold as important building materials for recycling. Nevertheless, 2.17 million tons of building debris remains to be cleared even two years after the earthquake.

A study on the management of disaster waste after 2016 Kumamoto earthquake was made to find the present situation in Kumamoto. It is generally recognized that Japan must prepare for an earthquake in the Nankai Trough and a potentially massive earthquake striking the Tokyo metropolitan area. The disaster scales are predicted to be much larger than that of the Great East Japan Earthquake. In addition to these large earthquakes, large-scale typhoons and flooding are predicted to increase because of climate change. Implementing measures for handling disaster waste is one of the key points for material cycle and waste management. Thanks to the tremendous efforts by many people in the stricken areas of the Kumamoto Earthquake, it is likely that treatment of the disaster waste will be accomplished within the target period of 2 years. Knowledge gained through experience with disasters such as the Kumamoto Earthquake should help us to prepare for future disasters, especially following points; 1) management of huge amount of destroyed houses and buildings, 2) establishment of treatment flow beyond the affected region, 3) effective support and receiving the support, 4) integration and/or standardization of the separation. Supports during the disaster are in terms of skill, expertise and logistics provided to the affected areas which need to be managed properly for the effective outcomes. Similarly, integration of different disaster waste separation is essential for the quality of recycled materials to maintain the uniform standard.

The findings and result of this thesis are important in determining the disaster waste quantities prior to the disaster event which can be used in planning process for effective management in terms of finding the storage points, sorting and recycling centers and finally dispose in safe area. This led to effective disposal of waste with reuse and recycling of useful resource leading to environmental benefits like reduction of depletion of resources, reduction of use of energy in processing new materials, reduction in greenhouse gases, reduction in disposal cost as well as increase the capacity of landfill.

5.2 Recommendation for the future research

As from the studies on disaster waste in the thesis about the unit generation rates of building of Kathmandu Valley, disaster waste management in Kathmandu Valley after Gorkha earthquake and disaster waste management after 2016 Kumamoto earthquake Japan and the study primarily suggest policies in management of disaster waste in Kathmandu Nepal as developing country and recommendation after 2016 Kumamoto earthquake of Japan as developed country.

Unit generation rates of the building of Kathmandu valley provides the information about the quantities of individual and total building waste from damaged buildings with the data of structural types, floor area, number of stories. These estimated amounts of building debris that must be cleared for emergency response after a disaster. This information is vital to pre-disaster planning in order to establish disaster management protocols for smooth recovery operations. Thus, it is recommended for the government of Nepal and local governments to utilize the findings of research in pre-disaster planning in order to establish disaster management protocols for smooth recovery operations. As the quantification and classification is the first step in planning for appropriate collection, sorting and treatment systems; the concern authorities are suggested to formulate appropriate cost-reducing strategies for the debris removal, treatment and utilization. It is also recommended for formulation of policies for recycling of different materials from the disaster waste as far as possible with encouragement of private sector in recycling; and formulate the standards to use recycled materials in public works as well as in private works. This will also enhance the post-earthquake reconstruction activities from systematic access to materials recycled from the disaster waste.

During the study of disaster waste management of Kathmandu Valley after the Gorkha earthquake in Kathmandu Nepal, there were no data or information from house owners, demolition contractors, or private developers provided to government agencies on the volume of debris generated, transported and disposed, or reused. Government agencies therefore did not obtain sufficient information about exact disposal methods and quantities of disaster debris generated in the core city area due to prioritizing issues other than the disposal of building debris after the main relief, recovery, and rehabilitation efforts. The reuse and recycling rate of materials from building debris varies significantly depending on the damage situation, area, and opinions of experts. Thus, it was recommended that the central government and the local bodies to update the records of type of buildings, contractors and private developers in their territory and put forward some policies for the management of debris prior to the possible disaster with method of collection, transportation, collection points, segregation, recycling and final disposal. It is also recommended for further analysis of reuse and recycling of materials from building debris and it's potential for supplementing traditional building materials. Furthermore, it is recommended for an evaluation of environmental impacts related to random building debris disposal and potential improvements is required for future safe debris management due to the concerns of disposal practice seen after Gorkha earthquake mostly down the cliff with potential landslide and illegal disposal in vacant land, river bank for possible contamination on soil and water.

The Government of Nepal has been working in disaster waste management and have published a report "Disaster Waste Management Policy, Strategy and Action Plan" with joint effort of United Nations Environment Program (UNEP) that include the strategies of with the objectives to minimize the waste generation; maximize reuse, recycling and material recovery; develop waste management practices; and ensure waste management is safe and effective. These strategies were planned to be solved by four stage prevention, preparedness, removal and recovery with actions like formulation of policies, revision of building codes, building damage assessment, disaster waste assessment, resource management/mobilization, capacity building promotion of 3R activities etc. with its implementation in short term (0-2 years), medium term (1-5 years) and long term (5-10 years). However, the implementation of the strategies is slow and weak. Thus, it is recommended to follow the action plan for effective implementation.

Form the study of disaster waste management after 2016 Kumamoto earthquake, it was found that the destruction caused and debris generated by the 2016 Kumamoto earthquake with the management aspect of disaster waste. Further elaboration is made on primary and secondary temporary storage sites for segregation and adoption of full-scale recycling systems with importance of networks of cooperative organization in dealing with disaster waste and comparative discussion for different aspect of disaster waste management in Kumamoto earthquake and other disasters. Knowledge gained from the experience of 2016 Kumamoto earthquake and its disaster waste management should help in preparing for future disasters and recommends in following points especially 1) management of huge amount of destroyed houses and buildings, 2) establishment of treatment flow beyond the affected region, 3) effective support and receiving the support, 4) integration and/or standardization of the separation. Integration and /or standardization can be achieved by developing a standard manual for each material type depending upon its potential treatment method (reuse, recycle or disposal) by putting a priority on reuse or recycling; environmental concern, capacity, treatment facilities and cost.

Further the experience of Kumamoto disaster waste management model can be implemented in Nepal for the treatment for Gorkha earthquake and for future disaster in terms of having strong policy and guidelines for disaster waste management, reuse or recycling guidelines and facilities, fixed plan and target by the government to complete treatment and disposal of disaster waste, support of the citizens and strong network among the different organizations to support after the disaster event to manage waste with skill, expertise and resource effectively. However, the nature of disaster waste and its treatment might differ due to the quantity, nature and location of the disaster. Thus, the guidelines and policies should be designed that suits for our disaster waste. Also, the formulation of appropriate policies that are acceptable in our scenario and awareness in management of disaster waste from policy makers to general level for all local entities of Nepal and for the provincial and central government is necessary.

Appendix

A. CASE STUDIES OF BUILDING DEBRIS MANAGEMENT PRACTICES IN KATHMANDU VALLEY

For the first part of the research, a case-study methodology was chosen, which involved direct observations in the field, interaction with different stakeholders, and meetings with the officers involved in damaged building assessment and building debris management.

These cities were selected within three districts (Kathmandu, Lalitpur, and Bhaktapur), with at least one city from each district represented. The selection also includes three main cities: Kathmandu Metropolitan City (KMC), Lalitpur Sub-Metropolitan City (LSMC), and Bhaktapur City, each in different districts. Similarly, smaller growing cities such as Sakhu of Shankharapur Municipality in Kathmandu district in the east, Lubhu of Mahalaxmi Municipality in Lalitpur district in the south, and Kirtipur Municipality of Kathmandu district in the west of Kathmandu Valley were selected outside the core area. The towns of Khokana and Bungmati in Lalitpur, damaged heritage sites, and Chobhar in Kathmandu City were also visited.

Three small cities Sakhu, Lubhu, and Kirtipur were selected outside the core area of Kathmandu Valley for interactions with local communities, field visits, and meeting with municipality personnel. Interactions with community, key-persons, municipality officers, and field visits were arranged and supported by the officers/staff of the local Non-Governmental Organization (NGO) working under OXFAM Nepal in three small out of core cities.

Similarly, to understand the building damage and building debris management in the core city area, Kathmandu Metropolitan City and Lalitpur Sub-Metropolitan City were chosen. Meetings with the Chief and Senior Engineer of the Environment Management Division of KMC (Kathmandu City) were conducted with field visits to the core Kathmandu city area and the temporary disposal point of Tundikhel. Similarly, meetings with officers from the Solid Waste Management Technical Support Center (SWMTSC) were held to collect information regarding the current building waste management practices and issues facing all cities of Kathmandu Valley. Also, meetings with Divisional Engineers of the Department of Urban Development and Building Construction (DUDBC) were held to gather information about the public buildings in Kathmandu Valley and related debris management.

Field observations alone were performed in the small towns of Khokana and Bungmati in Lalitpur district and the Bhaktapur Municipality area were performed in guidance of SWMTSC officer for the observations of damaged buildings, reuse of building materials, and debris management. Additionally, we made field observations of Kathmandu heritage sites, the core Kathmandu city area, and the government proposed disposal point (old limestone quarry) in Chobhar, Kathmandu district.

Firstly, interactions with key-persons of the city and the community were conducted to understand building damage, building waste generation, and its management. All relevant information regarding building waste, including methods of building demolition, demolition contractors and equipment, building waste management prior to the Gorkha earthquake, environmental effects, quantification methods, disposal methods, disposal points and distance, the reuse and recycling of building waste, and the management of hazardous waste, were gathered from key stakeholders by questionnaires and checklists; other information was recorded in a field book.

Additional statistical data and information were collected from municipalities and relevant offices. During the field visits, interactions with house owners were made with reference to key-persons of the city and relevant information was recorded. Photographs of the damaged buildings and debris deposition points were taken as a research resource. Supplementary information on building debris management was collected from randomly sampled key-persons, community persons, and house owners using questionnaires. A checklist was prepared for interviewing municipality engineers, environmentalists, divisional engineers, and ward office chiefs to collect information on building debris management in selected areas of Kathmandu Valley. Direct field visits were conducted to observe the current damage state and building waste management situation in the cities of Kathmandu Valley.

B. EFFECTIVE LAND AREA FOR DISASTER DEBRIS MANAGEMENT

S.N.	Program Sites	Total area (ha) from open space report	Effective area (ha) based on site evaluation	Remarks
1	Bagmati Corridor 4	1.59	1	Bagmati and Bishnumati Banks require some cut off distance to avoid bank landslip and discharge of debris to the river. Likewise, temples, drainage and roads, must be avoided
2	Bagmati Corridor 5	2.7	2.1	Bagmati Bank requires some cut off distance to avoid bank landslip and discharge of debris to the river. Likewise, roads and drainage and sewage lines must be avoided
3	Bagmati Corridor 6	0.63	0.3	Bagmati Bank requires some cut off distance to avoid bank landslip and discharge of debris to the river. Likewise, roads and drainage and sewage lines must be avoided
4	Ring road Maharajgunj Chabahil	17.4	6	Main road, side roads, entry to side access roads, drainage and electrical and telecommunication lines must be avoided. Only available space is the green belt on either side. The topography (fill up section and cut sections between Shanka park to Dumbarahi, Dhumbarai to suke Dhara, Dhobi Khola to Chabahil chouk) does not permit safe placement of debris
5	Shankha Park	1.75	1.3	Memorial Pillar must be avoided
6	Oxygenation Park	35.94	27.94	Solar panel and other office areas on the western side of the park must be avoided
7	Ringroad Balkumari Gwarko	7.82	3	Main road, side roads, entry to side access roads, drainage and electrical and telecommunication lines must be avoided. Only space available is the green belt on either side. The topography (fill up section between Manohara bridge to Gwarko on the western side) limits safe placement of debris
8	Ringroad Gwarko Satdobato	7.11	3.3	Main road, side roads, entry to side access roads, drainage and electrical and telecommunication lines must be avoided. Only available space is the green belt on either side
9	Ringroad Satdobato Ekantakuna	11.71	5	Main road, side roads, entry to side access roads, drainage and electrical and telecommunication lines must be avoided. Only available space is the green belt on either side. The topography (cut section near Ekantakuna) limits safe placement of debris

**From Table 2.3 of* "Final Report and Consultancy Service for "Environmental Impact Assessment (EIA) of Post-disaster Debris Collection, Disposal and Management Sites" by Nepal Environmental & Scientific Services [NESS] (P) Ltd. to International Organization for Migration (IOM), Nepal.

C. TEMPORARY DEBRIS COLLECTION CENTERS

Temporary debris disposal site in KMC

1. Tudhikhel south east corner premises
2. Lainchaur open space south east corner premises, ward no. 29
3. Daalu suspension bridge, open space of riverside, ward no. 19
4. Open space near biogas plant in Daalu, ward no 19
5. Open space of Hyumat, ward no. 12
6. Open space near Wansighat bridge ward no. 11
7. Open space near Kalimati bridge, ward no.13
8. Near Saaja Petrol Pump ward no. 14
9. Sitapaila Chowk, greenbelt, ward no. 15
10. Near compound of Banasthali School ward no.16
11. In front of Naptaul, Machha Pokhari Chowk-greenbelt, ward no. 16
12. Open space of police resident premises behind national police training center, ward no. 3
13. Greenbelt area in front of Maharajgunj Indreni Restaurant, ward no. 3
14. Open space of Bagmati Corridor, eastern corner of Guheswori Treatment Plant, ward no.8
15. Near police station behind maternity hospital, ward no. 11
16. Open space of Nandi Ratri School, ward no 1
17. Open space of Tinkune, ward no. 35
18. Open space of Diveshwori Town Planning area across Pepsicola Manahara river, ward no. 35

Large scale debris disposal:

1. Chobar empty land
2. Diveshwori Town Planning area across Pepsicola Manahara river

**From Annex IV of* "Disaster Waste: Addressing the Challenges in Nepal" by the Solid Waste Management Technical Support Center, 2015.

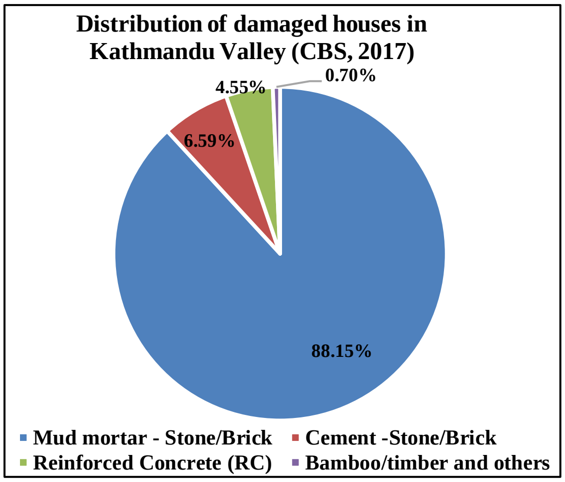
D. CURRENT STATE OF DEBRIS WASTE GENERATION AND MANAGEMENT

There was severe damage to buildings in Kathmandu Valley after the Gorkha Earthquake. Old houses, especially brick masonry buildings bonded in mud mortar with tile or corrugated iron sheet (CGI) roofing, were the most affected buildings. The proportion of damage to this type of buildings was more than 85%. Within brick masonry buildings, adobe brick (sun-dried brick) masonry in mud-bonded types were the most severely affected. Cement-bonded brick masonry buildings and reinforced concrete (RC) buildings are comparatively stronger buildings; however, these buildings suffered damage that might have been due to poor construction or the geology of the area. The proportion of damage among different types of buildings in Kathmandu Valley is presented in Figure 1.

The demolition of damaged buildings and debris removal commenced immediately after completion of the emergency response phase of the earthquake. According to the decision of the technical committee formed by the government for vulnerable building structures, demolishing the building structure is the responsibility of the house owner. If vulnerable structures could not be removed by the house owners, skilled technicians will remove vulnerable parts and the owner had to pay for the removal work (GoN, 2015b). However, the removal of vulnerable parts of buildings was made possible by the efforts of the Nepal Army, Armed Police Force, and international, skilled, voluntary support groups who removed vulnerable parts using hand tools and in some case machines such as excavators. The methods of post-earthquake building debris management in cities in the out of core Kathmandu Valley are described in Figure 2.

In the second phase, home owners and their neighbors cleared debris from their houses with the support of international NGOs such as OXFAM and their local partner NGOs, who provided technical assistance, tools, and safety gear for the safe demolition of damaged buildings. “Cash for Work” was the method adopted by these international NGOs, which benefitted people in two ways: firstly, demolition and debris removal was performed to enable new constructions; secondly, they received monetary support for hours worked during the emergency period.

Building debris from damaged buildings were then collected at the nearest road head. This collected building debris was transported and disposed of in areas designated by the municipality. For the loading and transportation, excavators, loaders, and transport trucks were provided voluntarily or the municipality provided fuel and subsidized hire prices. For the area where buildings were scattered and there was sufficient space for temporarily storing demolished building waste, people either disposed of the waste themselves or transported it after debris of the core city area was removed. The demolition and clearing of building debris was performed in up to four phases because the collected building debris obstructed access roads.



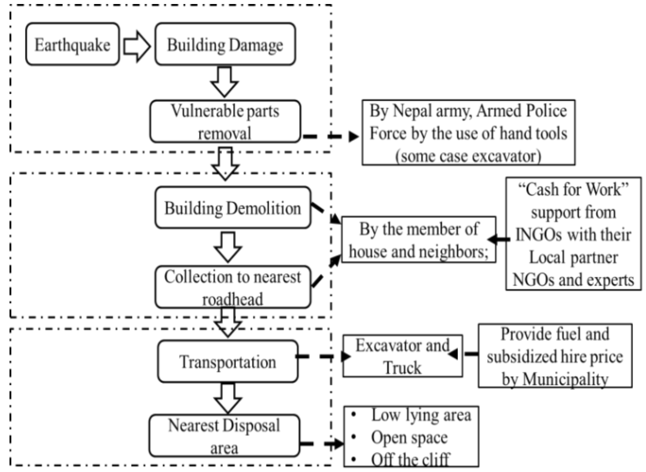


Figure 1: Distribution of damaged house types in Kathmandu Valley

Figure 2: Debris waste management in small cities of Kathmandu Valley

The same method was applied in many cities in the out of core Kathmandu Valley. In Kathmandu, no registered large private companies were available nor involved in demolishing and recycling building waste; demolition at a smaller scale was managed by local demolishers. For the core Kathmandu Valley area i.e. Kathmandu Metropolitan City and Lalitpur Sub-Metropolitan City, after the removal of vulnerable parts, local demolition contractors were hired by house owners to manage the debris. In some cases, local demolition experts made a contract for whole house demolition and disposal at a reduced price, salvaging all useful scraps from the house. In other cases, the contract was only for demolition and disposal. Examples of building damage, debris removal, and re-construction of monuments are shown in Figure 3.

It was observed that more than 50% of damaged buildings in Sakhu had yet to be demolished and cleared. Similarly, in Lubhu, only 3% of building debris had been cleared and reconstructed; 25% of the buildings were only debris-cleared; 62% of buildings had vulnerable parts removed but the debris was not cleared; and 10% of buildings still had vulnerable parts. Building debris from historical and archeological monuments was managed by the Department of Archaeology, Nepal. According to DUDBC, damage to high-rise buildings was observed but no high-rise buildings needed to be demolished in Kathmandu Valley.

(a) (b) (c)

Figure 3: (a) Damaged buildings and materials in Khokana, (b) debris removal from a house in Bhaktapur, and (c) damaged monument reconstruction in Bhaktapur

E. DISASTER DEBRIS DISPOSAL METHODS IN KATHMANDU VALLEY

a. **Low-lying land:** In this method of disposal, low elevation land or depressions are filled with debris to obtain a level surface or improved level compared to the previous land elevation. This is an open dumping method in areas without wastewater treatment facilities. Typically, this land is government land, which may not be marked for construction or other purposes in future except in some case. Also, private land owners may provide the land to improve the level for later use or sale as construction land.

b. **Down the cliff:** Kathmandu Valley lies in a hilly region of Nepal and displays a range of elevation; the average elevation of Kathmandu is 1400 m above sea level. The landforms in Kathmandu include plains, gentle slopes, elevated land, ridges and valleys formed by river erosion, and rivulets in the watershed drainage area. Cliffs form naturally within Kathmandu Valley, and are usually vacant, non-registered government land. Disaster debris is disposed of from the cliff top onto the slope. In most cases, disposed debris reaches a water course, with a high probability of water contamination. The debris disposal method is open dumping with no wastewater treatment measures. This disposal method involves a smaller reclaimed land area and future construction is typically not feasible.

c. **River banks:** Kathmandu valley consists of several major rivers, i.e. the Bagmati, Bishnumati, Dhobhikhola, and Manhara, and their tributaries. These rivers previously occupied a large land area during high flood periods; however, river discharge has decreased and flow is now confined to small areas, leaving large areas of vacant land on the river bank. These open banks on either side of the rivers are used as debris disposal points, especially in Kathmandu Core City. This disposal method is also open dumping with no wastewater treatment facility, resulting in highly likely water contamination. Typically, this disposal method protects the river bank from erosion. The reclaimed land can be used as recreational spots such as parks and walking trails in the core city area.

d. **Open vacant land:** Kathmandu valley contains a lot of vacant land occupied by the government for different purposes. There are also many areas not under registration by private owners or the government, which come under the direct ownership of local government. However, this vacant land, with no construction or designated use, was utilized by the public for debris disposal during the earthquake emergency period. This open vacant land might be a part of public parks, area adjacent to roads, or other unused vacant land. The disposal method is usually open dumping without any measures protecting against harmful leaching to the land nor wastewater treatment facilities. Unused vacant land often has potential for construction or other uses, so are typically used for temporary collection in core cities; however, debris deposited adjacent to parks could also be levelled for future use. Similarly, debris deposited on the sides of roads is usually levelled and used for sidewalks and gardens but other construction is not permitted as it will impede the right of way.

e. **Land development areas:** Kathmandu is the capital city of Nepal, and urbanization is very rapid in Kathmandu Valley. Many people migrate to the area in search of employment, education, health services, and many other reasons from all parts of the country. This creates significant land demand for private construction. Each year, private land developers develop agricultural land and other private land to sell for building construction purposes. During land development, the developers require large quantity of soil or debris to fill the land in depressions and obtain level ground. Thus, large quantities of building debris from the Gorkha earthquake were utilized for this purpose, mainly in areas outside of the ring road of Kathmandu Valley. Debris remover made double benefit of making money by debris removal from house owners and then again by selling the debris to land developers. This method is also open dumping with no treatment facility for wastewater leaching from the disposal area. The land can subsequently be used for building construction.

f. **Surfaces of earthen roads:** Most of the roads in the core city area of Kathmandu Valley are tarmacked; however, some internal roads of cities or those connecting rural areas to cities are mostly earthen roads. These roads have weak surfaces that are often damaged during the rainy season, impeding vehicular movement. Disaster debris are dumped on these damaged roads to create a hard surface because disaster debris predominantly contains broken bricks, stone, and concrete. This is also an open dumping method without any wastewater treatment. There is a chance of contamination in nearby water bodies by leaching from the elevated road surface. This is a good method of disaster debris reuse; however, a higher proportion of hard materials like brick, stone, and concrete is preferable.

g. **Foundations of new houses:** Due to rapid urbanization, many buildings are constructed each year in Kathmandu Valley to meet the housing demand. The groundwater table in Kathmandu Valley is high, so the height of foundations is increased to prevent damp. Thus, a large quantity of filling material is required for the foundations of new houses. Disaster debris was used as foundation fill after the Gorkha earthquake in Kathmandu Valley. The contractors responsible for house building collect debris either from demolition sites of earthquake-damaged buildings or temporary debris collection points. This method is also uncontrolled dumping; however, the material is enclosed within the foundation. There is no mechanism to treat wastewater leaching from the debris deposit and thus there is a high chance of contamination of both land and groundwater.

h. **Backfill of road structures:** For small cities outside the core city area, extensive improvement work on roads and road structures has been conducted. During these improvements, along with the construction of road structures like culverts and retaining walls, a large quantity of filling material is required to provide level, wide roads for the effective function of these structures. Disaster debris near the cities were collected and used to fill these structures. This deposition method is open and uncontrolled without provision for wastewater treatment.

i. **Filling of traditional ponds:** There are many ancient ponds of historical importance in Kathmandu Valley. These ponds still serve as a water reserve and are ecologically valuable. However, most of the ponds are dry due to lack of structural maintenance of pond, lack of recharging, and water extraction measures for domestic use. Such ponds in one city in Kathmandu valley were found to partly contain disaster debris deposited temporarily from the surrounding area. This is also an open dumping method without no measures for treating contaminants leaching from the deposit. These harmful contaminants might affect the pond once the water is recharged after the maintenance of pond.

j. **Soil-excavated pits of brick factories:** There are many brick factories in the outer region of Kathmandu Valley that supply bricks for construction work in the area. In one of the major cities of Kathmandu Valley (Bhaktapur), brick factories are located nearer to the main city area and the pits left after excavation of clay for brick production are filled with debris generated in the city. This is also an open dumping method without any measures for preventing leaching from the disaster debris to the land and groundwater. Usually, pit filling generates a levelled land surface that can be sold for future construction.

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Kyoto, April, 2019

Scientific Publications and Conferences

Original Scientific Publications

1. Poudel, R., Hirai, Y., Asari, M., & Sakai, S.-i. (2019). Field study of disaster waste management and disposal status of debris after Gorkha Earthquake in Kathmandu, Nepal. *Journal of Material Cycles and Waste Management*, doi: 10.1007/s10163-019-00835-3

2. Sakai, S.-i.., Poudel, R., Asari, M., & Kirikawa, T. (2018). Disaster waste management after the 2016 Kumamoto Earthquake: A mini-review of earthquake waste management and the Kumamoto experience. Waste Management & Research, doi: 10.1177/0734242X18815948

3. Poudel, R., Hirai, Y., Asari, M., & Sakai, S.-i., (2018). Establishment of unit generation rates of building debris in Kathmandu Valley, Nepal, after the Gorkha earthquake. *Journal of Material Cycles and Waste Management*, *Vol. 20(3):1663–1675*. doi: 10.1007/s10163-018-0731-8

Conferences/Scientific meetings

1. Poudel, R., Hirai, Y., Asari, M., & Sakai, S.-i. (2018). Disaster Waste Generation Rates of Buildings in Kathmandu Valley, Nepal after 2015 Gorkha Earthquake. 2018 Spring Scientific Conference by Korea Society of Waste Management , May 9-11, 2018, Gwangyang , Republic of Korea. **Oral and Poster (Hybrid)**

2. Poudel, R., Hirai, Y., Asari, M., & Sakai, S.-i. (2017). Unit Generation Rates for Disaster Waste and Estimation of Organic Waste-Case in 35 Wards of Kathmandu City. The 4th International Conference on Final Sinks, October 24-27, 2017, Kyoto, Japan. **Poster**

3. Poudel, R., Hirai, Y., Asari, M., & Sakai, S.-i. (2017). Disaster Waste Management Situation in Kathmandu Nepal: Two Years after the Gorkha Earthquake. 39th Symposium of The Association of Environmental & Sanitary Engineering Research, July 28-29, 2017, Kyoto University, Kyoto, Japan. **Oral and Poster (Hybrid)**

4. Poudel, R., Hirai, Y., Asari, M., & Sakai, S.-i. (2017). Establishment of unit generation rates of building debris in Kathmandu Valley, Nepal after Gorkha Earthquake. 4th 3R International Scientific Conference on Material Cycles and Waste Management, March 8-10, 2017, New Delhi, India. **Oral**

5. Poudel, R., Hirai, Y., Asari, M., & Sakai, S.-i. (2017). Evaluation of building debris of Kathmandu Valley, Nepal after Gorkha Earthquake and its potential treatment option. 3rd 3R International Scientific Conference on Material Cycles and Waste Management, March 9-11, 2016, Hanoi, Vietnam. **Oral**