Evaluation of Post-Earthquake, Tsunami, and Liquefaction Disaster Waste Management in Palu

Tezario Chandra Putra Parura¹, Benno Rahardyan²

¹ Master Programme of Environmental Engineering, Institut Teknologi Bandung, Indonesia

² Air and Waste Management Research Group, Institut Teknologi Bandung, Indonesia

Abstract. The Central Sulawesi region is known as the meeting place for three of the world's main tectonics. As a result, the region is prone to natural disasters, especially those caused by the movement of these plates, which has prompted a shift in the Palu-Koro Fault. This also caused the 7.4 magnitude earthquake that devastated the coastal area of Palu Bay on September 28, 2018. Post-disaster waste management is one of the most important operational management systems ever developed to help affected communities and restore conditions to a stable situation after the disaster. In this study, the estimation of disaster waste generation was carried. In addition, an evaluation of disaster waste management was carried out as well as the formulation of disaster waste management mitigation, particularly earthquake, tsunami and liquefaction disasters. The estimated generation of construction disaster waste is 80,894,4 m³ and non-construction waste is 52,305.6 m³. Disaster waste management evaluation indicate that the lowest value in the evaluation aspect is in the aspect of community participation (30%) and the Financing aspect (37.5%). The establishment of a disaster waste management system will focus on the preparation of technical guidelines and Standard Operating Procedures (SOPs) on disaster waste management.

1. Introduction

Indonesia, which consists of islands, has a very high disaster potential and also varies in types of disasters. Potential disasters in Indonesia can be grouped into 2 main groups, namely the main potential hazards and the potential for collateral hazards [1]. Potential disasters in Indonesia caused by seismic activity are discussed in Figure 1 below [2].

location there had been an earthquake, tsunami and liquefaction disaster some time ago. The Palu City landscape stretches extending from East to West with an area of 395.06 Km². Astronomically, Palu is located in the position of 119.45 - 121.15 East and 0.36 - 0.56 South Latitude. The city of Palu is divided into 8 districts and 45 villages. The sub-districts are West hammer sub-district, South Palu sub-district, East Palu sub-district, North Palu sub-district, Mantikulore sub-district, Ulujadi sub-district, Tatanga sub-district, and Tawaeli sub-district. The population of Palu City in 2017 is 379,782 people with the highest population density is in East Palu District [6].

Fig. 2. Administration map of Palu

2. Methodology

2.1 Data Collection

The primary data collection method used refers to the study of Evaluation of Disaster Resilience on Waste Management in Developing Countries [7]. Primary data collected were obtained from the results of sampling in the field using the Observation, Questionnaire, and Interview methods. From the collection of primary data, it can be estimated that the generation of disaster waste in terms of volume and characteristics.

Table 1. Structure of questionnaire

Criteria	No	Variable
Characteristics of respondents	Q ₁	Gender
	Q ₂	Level of education
	Q ₃	Type of work
	Q ₄	Post disaster status and living conditions
	Q ₅	Area of house buildings
	Q ₆	Specific type of disaster affected
Post-disaster construction waste management	Q ₇	Waste management actions taken
	Q ₈	Estimated amount / volume of waste
	Q ₉	Estimated waste composition
Post-disaster non construction	Q ₁₀	Containers used to collect waste before the disaster

Criteria	No	Variable
waste management		
	Q ₁₁	Containers used to collect disaster waste
	Q ₁₂	Estimated amount / volume of waste
	Q ₁₃	Estimated waste composition
Willingness and participation of respondents in term of post-disaster waste management	Q ₁₄	Level of satisfaction with disaster waste management by the Government disaster waste management
	Q ₁₅	Level of involvement in disaster waste management
	Q ₁₆	Existing disaster waste management
	Q ₁₇	Sorting of disaster waste management
	Q ₁₈	Landfills and conveyances used
Mitigation of disasters and disaster debris	Q ₁₉	Steps in anticipating disaster waste if re-occurring in the future
	Q ₂₀	Willingness to move to safer place

The sampling point of the respondent is shown in the Figure 3 below

Fig 3. The sampling point of the respondent

The secondary data needed includes data from several agencies that are domiciled as information providers to support the completeness of the data, including:

1. Estimated generation of construction waste, data that needs to be collected is data on the amount of infrastructure damage due to the disaster in Palu.
2. Operational technical aspects, data that needs to be collected and needed include data on waste disposal, garbage collection, garbage removal, garbage transportation, waste treatment, final disposal of waste, and service coverage areas.
3. Non-technical aspects, data that needs to be collected and are required include:
 - Regulatory aspects, the data needed is regulations referenced related to disaster waste management in the study area, both regulations from the central and regional governments.

- Institutional aspects, data needed related to waste management institutions such as the structure and form of the Institution, the main tasks and functions, the number of personnel, and their authority.
- Funding aspects, the data needed are sources of financing, including waste fees and the amount of costs incurred for disaster waste management.

2.2 Data Analysis

2.2.1 Analysis of estimated waste generation

For non-construction disaster waste estimation, the analysis is carried out using descriptive analysis method which aims to find a description of the existing conditions of waste management before and after disaster in the study area and to know the estimation of disaster waste generation, where the data collection is carried out with historical research principles to explain the data ago or retrospectively. The analysis was conducted based on the respondents' answers in the interview, as well as from the secondary data available. This evaluation was carried out using a descriptive analysis method that aims to find a picture of the existing conditions of waste management before and after a disaster in the study area. Analysis conducted based on the frequency distribution of respondents' answers and responses to the questions in the questionnaire. The steps in conducting this descriptive analysis include Editing, Tabulating, and Presenting Data.

For construction disaster waste, in addition to using questionnaire analysis and interviews, the estimation is done using data on the amount of damage to existing buildings. The amount of damage to the building will be multiplied by the function of building damage [8] where the function of building damage will be different in the type of building damage, namely in buildings that are damaged all parts or damaged some parts and mass per unit in this case is concrete because buildings in the city of Palu are dominated by concrete buildings. Estimates of disaster waste generation with construction waste characteristics will be calculated using the equation below [9].

$$\text{Quantity of Construction Waste} = \frac{\text{Number of building damaged} \times \text{Damage function} \times \text{Mass per unit}}{(1)}$$

2.2.2 Analysis of estimated waste management expenses

From the description of the existing conditions of disaster waste management, it can be evaluated regarding the financing aspects. Analysis of financing needs at the research location is done by calculating the financing components in waste management, including:

1. Waste sweeping fee

Obtained from the amount of costs incurred for sweeping officer salaries and costs required for the purchase of sweeping equipment such as brooms, dustpan, and trash cans. This fee covers the cost of cleaning up the garbage in the affected area.

2. Waste collection fees

Represents the total costs incurred for salaries / salaries of garbage collection employees, equipment depreciation costs, operational costs (vehicle fuel), maintenance costs (service and painting), and collecting equipment administration costs (payment of vehicle tax and vehicle insurance). The cost of depreciating a garbage collection tool can be calculated by the following equation.

$$\text{Tool depreciation} = \frac{\text{Purchase price} - (\text{Final price} \times \text{Number of tools})}{\text{Tool lifetime}} \quad (2)$$

3. Waste transportation costs

Represents the total costs incurred for salaries of garbage transport employees, depreciation costs, operational costs, and maintenance costs of transportation equipment.

4. Waste processing costs

Costs incurred for the final process of processing waste include 3R waste processing fees at Temporary Storage.

5. Management fees for waste management

Total costs incurred for managing employee salaries and costs incurred for administrative purposes such as stationery.

2.2.3 Evaluation of disaster waste management and disaster waste mitigation

From the description of the existing conditions of disaster waste management it can be evaluated regarding the advantages and disadvantages in the disaster waste management system starting from operational technical aspects and non-technical aspects including institutional aspects, aspects of community participation, and financing aspects. Assessment of system performance disaster waste management is carried out by setting indicators as a reference for the assessment to be carried out. Determination of indicators is done through stages of identification and verification-justification.

Table 2. Assesment indicators in evaluating disaster waste management

Aspects	Assessment Indicators
Operational technical aspects	<ol style="list-style-type: none"> 1. Coverage of solid waste services after a disaster 2. The amount of disaster waste managed 3. Availability of infrastructure 4. Schedule of disaster waste collection and transportation 5. Frequency of disaster waste collection and transportation
Regulatory aspects	<ol style="list-style-type: none"> 1. The existence of regulations requiring disaster waste management 2. The existence of regulations that govern disaster management institutions 3. The existence of regulations regarding community involvement in disaster waste management

	<p>4. The existence of regulations regarding the involvement of third parties in disaster waste management</p> <p>5. The level of application of regulations / policies</p>
Institutional aspects	<p>1. The existence of community education facilities</p> <p>2. The existence of a third party in disaster waste management</p> <p>3. The existence of supervision and monitoring</p> <p>4. The existence of experts</p> <p>5. Number of workers</p>
Financial aspects	<p>1. Allocation of funds for disaster waste management</p> <p>2. Adequacy of management costs</p>
Community participation aspects	<p>1. Community satisfaction with disaster waste management</p> <p>2. Community knowledge about the importance of involvement in disaster waste management</p> <p>3. Community participation in disaster waste management</p> <p>4. The existence of public complaints methods</p> <p>5. Community knowledge about appropriate methods of disaster waste management</p>

3. Results and Discussion

3.1 Background on Palu City Disaster

The City of Palu and its surroundings are alluvial plains that extend north-south and are limited by slopes and ridges on both sides of the valley and in the middle of the valley the Salo River flows. This plain is dominated by Holocene alluvium lithology units consisting of mud, clay, sand, gravel and crust. In addition, there is the Pakuli Formation which is Pliocene-age consisting of conglomerates and local sandstones of carbon clay which calls Molasa Sulawesi. Older rocks of the Upper Miocene Pakuli Formation, namely the Lariang Formation consisting of conglomerates, sandstone inserts, claystone, local tuff, mudstone, limestone, coral and marl. This rock by is also included in the Molasa Sulawesi unit [10]. Under the Lariang Formation rocks are already occupied by the Granite Complex and Diorite Complex as well as the metamorphic rocks of the Latimojong Formation, the Wana Complex and the Gumbasa Complex. In the Geomorphological Map the presence of alluvial fans is

identified on the right and left sides of the hammer valley where the alluvial fan flow pattern leads to the Palu valley.

From this condition it can be interpreted that the sedimentation process is very strong leading to the Palu Valley with the possibility of ground movement in areas of high topographic contrast and non-compact rocks. The tectonic and geological conditions above resulted in the Palu City area and its surroundings having a relatively high vulnerability to geological disasters. This region is an earthquake-prone region of MMI scale VI-VII. Likewise from the earthquake data recording, it appears that in this region there have been no less than 7 (seven) times of destructive earthquakes since 1900. The analysis of the earthquake for earthquakes on 28 September 2018 showed three sets of hypocenter namely a collection of hypocenter 1, 2 and 3. Collection of the hypocenter reflects that the Palu-Koro fault that was active in the earthquake consisted of three segments namely the Tambu-Talise-Bora Segment (north and center), the Gumbasa - Kulawi Segment (south), as seen in Figure 4. It triggered earthquake 7, 4SR and followed by aftershocks namely the tsunami and liquefaction [11].

Fig. 4. Palu active fault

Table 3. The amount of damaged houses due to natural disasters in Palu

Building Type	Condition				Total
	Lightly Damaged	Moderately Damaged	Heavily Damaged	Lost	
House	17.293	12.717	9.181	3.673	42.864
Health facility	18	20	3	2	43
Education facility	165	114	107	0	386
TOTAL	17.476	12.851	9.291	3.675	43.293

Fig. 5. Interpretation of building damage (a) affected by liquefaction in the Balaroa area (40 ha), (b) affected by liquefaction in the Petobo area (181.21 ha), and (c) affected by the tsunami (1267.14 ha)

Table 4. Estimated construction waste due to disaster in Palu

Type of Damaged	Amount of Damaged House	Damaged Function	Mass per unit (ton/dwelling)	Estimated Generation Waste (ton)
Lightly – Moderate	30.327	0,2	12	72,784.8
Heavy - Lost	12.966	0,78	12	121,361.76
TOTAL				194,146.56 equivalent to 80,894.4 ton

3.2 Estimated Generation and Composition of Disaster Waste

Construction waste is a type of waste arising from disasters where the quantity is dominant considering the type of disaster that occurred in Palu City. Estimation is carried out using data on the amount of damage to houses / buildings due to disaster as shown in Table 3.

Damage to buildings as a result of natural disasters in Palu will also be interpreted in the form of a map in Figure 5.

From the data on the amount of damaged buildings described above, we can estimate the generation of

construction waste due to disasters. Estimation is done by using the coefficient of intensity of building material which is assumed that the majority of building material is concrete with known concrete mass per unit, and the damage function is divided into two categories, Lightly – Moderate Damage and Heavy Damaged - Lost [10]. The results of construction waste estimation due to disaster are shown in Table 4 that is 194,146.56 ton and if converted into units of volume (with known concrete density) then is equivalent to 80,894.4 m³.

Composition of construction waste are shown in Figure 6.

Fig. 6. Composition of construction waste

Estimation of non-construction disaster waste generation and composition is done by using descriptive analysis method which aims to find a picture of the existing conditions of waste management before and after disaster in the study area and to know the estimation of disaster waste generation, where the data collection is carried out using historical research principles to explain the data ago or retrospectively. Analysis was carried out based on respondents answers in the questionnaire and interview. At the time of the emergency response, the transportation of waste becomes 8 shifts. From the interview it is known that waste transportation carried out during the emergency response period is 133,200 m³. Therefore, it can be calculated that the non-construction waste generated is 52,305.6 m³. Composition of non-construction waste are shown in Figure 7.

Fig. 7. Composition of non-construction waste

3.3 Estimation Disaster Waste Management Burdens in Financing Units

The financing aspect is a driving force so that the wheels of the waste management system in the affected area can move smoothly. It is hoped that the waste management system, especially those implemented and alerted to disaster prone areas will lead to 'self-financing', including the formation of regional companies. Based on preliminary interviews with the Waste Management Section of the City of Environment and Cleanliness of Palu City, the financing of disaster waste management in disaster affected areas is sourced from the Disaster Emergency Response Fund taken from the State Expenditure Budget through the National Disaster Management Agency, but its operations are handed over to the relevant agencies, that is the Department of Environment and Cleanliness of the City of Palu. Therefore, financing of disaster waste management in the city of Palu includes (1) sweeping costs; (2) Collection Fees; (3) Transportation Costs; (4) Processing costs at the landfill; and (5) Management costs. The operational costs incurred in managing waste in Palu City are charged to the Palu City Regional Revenue Budget (APBD). From these costs, a holistic waste management operational cost

Table 5. Palu existing waste management cost for 2017

No.	Waste Management Component	Cost	Percentage
1	Sweeping	Rp. 1.010.125.000,-	10.95%
2	Collecting	Rp. 302.732.000,-	3.28%
3	Transportation	Rp. 7.470.240.000,-	80.95%
4	Final disposal	Rp. 361.172.000,-	3.91%
5	Management	Rp. 84.000.000,-	0.91%
	TOTAL	Rp. 9.228.229.000,-	100%

Table 6. Cost component of disaster waste management

Generated waste (m ³)	Total Cost	Component	Cost by component
133,200	Rp3,507,991,160.96	Sweeping	Rp384,125,032
		Collecting	Rp115,062,110
		Transportation	Rp2,839,718,845
		Final disposal	Rp137,162,454
		Management	Rp31,922,720

can be calculated including the depreciation value of the assets of waste management infrastructure. The recapitulation of the results of calculations of costs incurred for waste management in the City of Palu for 2017 can be seen in the Table 5. After calculating the waste management costs per unit volume, the disaster waste management costs can be calculated as shown in Table 6.

3.4 Evaluation of Disaster Waste Management and Disaster Waste Management Mitigation

Evaluation is a series of activities comparing the realization of inputs, outputs, and outcomes against plans and standards [12]. In general, evaluation activities are carried out to assess the efficiency, effectiveness, benefits, impacts, and sustainability of a program by setting indicators and targets for the success of the activity. An assessment of the performance of a disaster waste management system is carried out by setting indicators as a reference for the assessment to be carried out. Determination of indicators is done through the stages of identification and verification-justification. In verifying and justifying indicators, the researcher prepares a definition in grouping the operational aspects, policy aspects, institutional aspects, financial aspects, socio-cultural aspects and community participation. Based on assessments that have been made by observation and interviews with relevant parties, the assessment values obtained for each aspect of the disaster waste management system are shown in the Table 7.

Table 7. The results of disaster waste management systems assessment

Aspects	Indicator	Answer	Score (%)	Total
Operational	TO1	D	15	55
	TO2	C	10	
	TO3	B	5	
	TO4	C	20	
	TO5	B	5	
Policy	R1	C	10	60
	R2	C	10	
	R3	A	0	
	R4	C	20	
	R5	C	20	
Institutional	K1	C	20	80
	K2	C	20	
	K3	C	20	
	K4	B	10	
	K5	B	10	
Financial	P1	B	10	37,5
	P2	B	5	
Community participation	PM1	B	5	30
	PM2	D	15	
	PM3	B	5	
	PM4	A	0	
	PM5	B	5	
TOTAL				52,5

To make it easier to interpret the results of the assessment of each aspect of the assessment in the disaster waste management system in Palu in accordance with existing

indicators then the results of the assessment will be displayed in the form of diagrams shown in Figure 8.

Fig. 8. Comparative diagram of the evaluation aspects of the disaster waste management system in Palu

Based on Table 7 and Figure 8, it can be seen that the lowest value in the evaluation aspect is in the aspect of community participation (30%) and the Financing aspect (37.5%) that indicate the constraint factors found in the aspect Community participation and Financing aspects. In the aspect of community participation, the deep sadness caused by the earthquake, tsunami and liquefaction caused many people to experience psychological disorders such as depression, depressed mood, depression and trauma. Based on that, the majority of people affected by disasters pay less attention to disaster waste management. In the aspect of Financing, the main obstacle faced is the disproportionate allocation of financing for disaster waste management. Under normal conditions, the management of municipal solid waste in Palu conducted by the Palu City Government through the Department of the Environment uses funding sources from the Palu City Regional Revenue Budget (APBD), where the budget is allocated to manage solid waste with normal generation, not due to disaster. So that when there is a spike in waste generation due to disaster, the budget is not proportional to managing disaster waste. From interviews with disaster management, the available budget is only sufficient <50% of the costs needed for disaster waste management. The lack of a disaster waste management budget consequently affects the operational technical aspects of disaster waste management.

3.5 Standard Operating Procedure for Disaster Waste Management in Palu

The natural disaster of the earthquake, tsunami and liquefaction in Palu occurred on September 28, 2018, so that steps in handling waste disasters have been described and evaluated in the previous chapter. Therefore, the establishment of a disaster waste management system will focus on the preparation of technical guidelines and Standard Operating Procedures (SOPs) on disaster waste management that can be activated and implemented when natural disasters again hit the City of Palu. In addition, technical guidelines and SOPs prepared can also be applied to other disaster affected areas and adapted to the type of disaster and local area characteristics. In line with disaster management activities, disaster waste management is also carried out in four phases.

Phase 1 is an Emergency Response phase that is focused in two stages, namely in the range 0 - 72 hours after a disaster called "Immediate actions" and in the range of more than 72 hours after a disaster called "Short term actions". In the range of 0 - 72 hours or immediate actions, the first step to managing disaster waste is to make a hazard ranking that can arise due to disaster waste. After 72 hours, then the steps to disaster waste management that need to be done is quick assessment to provide information related to taking further waste handling decisions. In the 72 hour period after the disaster, the waste management must be able to scale priority actions where each identified waste stream is ranked according to (1) the location of appropriate waste disposal for disposal of various types of waste in the emergency phase according to their composition and characteristics, and must be immediately a site feasibility assessment is carried out regarding the capacity and rapid environmental assessment before use. If there is no landfill available, then a temporary landfill or landfill can be specifically designated; (2) Clean the main roads as access for disaster victims' assistance and access to disaster waste management. It is ideal that disaster arising must remain within the affected area and cannot be removed before identification of the location of the disposed waste disposal is complete; (3) in disaster waste management, all equipment available from across sectors must be empowered. If heavy equipment such as trucks and excavators cannot be used due to accessibility reasons, wheelbarrows and wooden carts can be used as alternatives; (4) Any resources available for resolving priority problems that have been identified previously must be used as needed.

Phase 2 is an Early recovery phase. In phase 2 it is laid the foundation for the disaster waste management system that will be run during the initial recovery phase until the recovery phase. In this phase also addressed the main problems such as the choice of disaster waste disposal location according to the type and characteristics of waste, streamlining logistics in waste collection activities, as well as activities for reuse and recycling of waste. The efforts carried out are based on the results of the assessment and study in Phase 1 which are then developed to be more detailed and in-depth with an emphasis on long-term solutions. In this phase, the location of the processing and final disposal of disaster waste is carried out, starting the process of collecting and transporting waste, and starting communication with the public regarding the procedure for reuse and recycle of waste. The choice of disaster landfill location that can be used when a disaster occurs in Palu City is in the Kawatuna landfill area which is currently functioning as an urban landfill with specifications in Zone 3 that have not been used with an area of 12,584 m². The selection of this location is based on considerations that have been reviewed as well as the completeness of the waste processing equipment which from the beginning was in the landfill site. The recommended layout for a disaster landfill is shown in Figure 9.

Fig. 9. Recommended layout for disaster landfills

Phase 3 is a Recovery phase. This phase 3 will implement a disaster waste management system that has been designed in Phase 2, and will continue to be monitored and evaluated on an ongoing basis. Important steps that must be taken in this phase are:

- Develop and implement a communication plan between the Government (waste management) and the community to ensure that the disaster management system that has been and will be carried out is in line with the expectations and needs of the community.
- Re-procurement or repair of processing installations, machinery, or tools and infrastructure used in waste management that was previously damaged or lost due to disaster.
- If needed, conduct training for disaster waste management operators so that it can support the implementation of disaster waste management going well.
- Integrate the disaster waste management system into the management of household and similar household solid waste under normal conditions and the system has been upgraded.
- The output of this phase is that all disaster waste has been well managed with a 100% service target through collection, final processing, reuse, and recycling.

Phase 4 is a Contingency planning phase. This phase does not focus on disaster waste emergency response, but rather helps to bridge the response, recovery, and long-term system development so that this phase is an important investment phase. Contingency planning can be carried out during the recovery phase or as a preparatory step before a disaster (mitigation) occurs. The purpose of this phase is to develop a Contingency Plan and Mitigation for disaster waste management that is used to assist the community and the Government in determining appropriate and optimal management options based on the events of the disaster that occurred before. The mitigation plan can identify options and resources used in disaster waste management so that it can save budget, increase administrative efficiency, and increase control and effectiveness in disaster waste management. One of the

Table 8. Distribution of Palu City Disaster Prone Areas (ZRB) and their extent

Zone	Explanation	Area (ha)
ZRB 1	Bright yellow: Development zone	5,239.005
ZRB 2	Yellow: Conditional zone	28,507.33
ZRB 3	Dark yellow: Restricted zone	2,215.728
ZRB 4	Red: Forbidden zone	691.34
Total		36,653.403

Fig. 10. Map of Palu City Disaster Prone Areas

important things to do in this phase is to prepare disaster-prone zoning that can be used as a reference for the community so that it can avoid areas that are considered prone to disasters to become settlements and other public activities to minimize the impact of disasters, one of which is disaster waste. The Palu Disaster Prone Zone Map has been prepared with the division of 4 zones with different zone areas which are shown in Table 8. The determination of Palu's disaster-prone zones is also displayed in the form of a map presented in Figure 10.

After carrying out the entire phase in disaster waste management, it is next important to have a sustainable waste management strategy from the recovery phase to the continuous management of household waste in the area. The key to sustainability is the involvement of the community and local government in all aspects of waste management, these aspects are:

- Ensure the technical capabilities of the local waste manager where local capabilities and capacities must be built in such a way that once the disaster waste management activity is complete, there is still sufficient technical capability to run the waste management system going forward.
- Financial capability where the waste management system must continue to run after going through the recovery phase by using costs from the public sector to ensure the sustainability of waste management.

In addition to community involvement, an important thing to consider to achieve sustainable waste management is the transfer of waste management. The logging aspects include:

- Governmental cross-sectoral transition, when the disaster waste management system is carried out is a collaboration between the regional government and the central government and assisted with members of the Army and National Police, then after the disaster waste management phase is declared complete, the authority must be handed over to the local government as the waste manager to continue Regional waste management activities as a form of public service.
- Community-based organizations (local NGOs), in which the disaster waste management system is taken over by local NGOs to continue non-governmental activities with national or international funding.

In general, the Standard Operating Procedures for the waste management system recommended for implementation in Palu City can be illustrated in the flow diagram presented in Figure 11.

4. Conclusion

Disaster waste management is important to do as part of disaster emergency response. The results of construction waste estimation due to disaster is 194,146.56 ton and if converted into units of volume (with known concrete density) then is equivalent to 80,894.4 m³. Construction waste are consist of Concrete, Timber, Glass, Metal, Gypsum, and Ceramic.

From the interview it is known that waste transportation carried out during the emergency response period is 133,200 m³. Therefore, it can be calculated that the non-construction waste generated is 52,305.6 m³. Non construction waste are consist of Textil, Electronic device, Paper, Animal carcase, Plastic and rubber, and also Vegetation.

The total cost for waste management in the City of Palu for 2017 is Rp. 9.228.229.000,-. After calculating the waste management costs per unit volume, the disaster waste management costs can be calculated and the cost is Rp3,507,991,160.96 with the percentage of each aspect is 10.95% of the sweeping aspect, 3.28% of the collection aspect, 80.95% of the transportation aspect, 3.91% of the final disposal aspect, and 0.91% of the management aspect.

The lowest value in the evaluation aspect is in the aspect of community participation (30%) and the Financing aspect (37.5%) where based on the value of the existing indicators indicate the constraint factors found in the aspect Community participation and Financing aspects.

The establishment of a disaster waste management system will focus on the preparation of technical guidelines and Standard Operating Procedures (SOPs) on disaster waste management that can be activated and implemented when natural disasters again hit the City of Palu. In addition, technical guidelines and SOPs prepared can also be applied to other disaster affected areas and adapted to the type of disaster and local area characteristics. In line with disaster management activities, disaster waste management is also carried out in four phases, there are Emergency phase, Early recovery phase, Recovery phase, and Contingency planning phase.

References

1. Bakornas PBP. *Pedoman Umum Penanggulangan Bencana dan Penanganan Pengungsi* (Jakarta, 2001)
2. Badan Meteorologi, Klimatologi, dan Geofisika. *Peta Seismisitas Indonesia* (Bidang Seismologi Teknik, Jakarta, 2019)
3. Akgün, F. Gümüşbuğa, B. Tansel. *Risk based facility location by using fault tree analysis in disaster management* (Omega 52, 2015)
4. Coppola, D. *Introduction to International Disaster Management* (2011)
5. Yasumasa, T. *Disaster Waste Management*. (Hokkaido University, 2017)
6. Badan Pusat Statistik. *Kota Palu Dalam Angka* (Palu, 2018)
7. Maryono. *Evaluation of Disaster Resilience on Waste Management in Developing Countries* (Kyushu University, 2015)
8. Tokyo Metropolitan Government. *Tokyo's History, Geography, and Population*
9. Tabata, T. *Environmental and Economic Evaluation of Pre-Disaster Plans for Disaster Waste Management: Case Study of Minami-Ise, Japan* (2016)
10. Sukanto, R. *Peta Geologi Tinjau Lembar Palu Sulawesi* (Pusat Penelitian dan Pengembangan Geologi, Bandung, 1973)
11. Soehaimi. *Genetika Gempabumi* (Badan Geologi Kementerian ESDM, Bandung, 2018)
12. Adiyoso, W. *Manajemen Bencana: Pengantar dan isu-isu Strategis* (Bumi Aksara, Jakarta, 2018)