IMPROVEMENT OF MUNICIPAL SOLID WASTE MANAGEMENT USING LIFE CYCLE ASSESSMENT APPROACH FOR REDUCING HOUSEHOLD HAZARDOUS WASTE CONTAMINATION TO ENVIRONMENT IN INDONESIA: A CASE STUDY OF PADANG CITY

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ABSTRACT

This paper evaluates the level of household hazardous waste (HHW) contamination due to the current local Municipal Solid Waste Management (MSWM) practices and proposes applicable solutions through improvement of current recycling facilities and the inclusion of HHW management system in Indonesia. HHW contamination is indicated by the concentration of Hg, Pb and Cd at Padang Municipal Landfill. Evaluation on current MSWM shows that Padang City does not practice source-separated collection, enough waste recycling activities, and HHW management system. Those conditions result in HHW-contaminated waste, which causes the concentration of Hg, Pb, and Cd at the landfill site exceeds the national maximum limit. The LCA model, Integrated Solid Waste Management Model (ISWM), was used for comparing the heavy metal concentrations of current MSWM and 2 improved scenarios. The LCA on improved scenario #1 results in the reduced concentration of the heavy metals by around 12.76%. Meanwhile, the inclusion of HHW management system would further reduce the heavy metal concentrations by around 60.74% as suggested by scenario #2. It may be applied to Padang City and other Indonesian Cities with some changes to a current system such as establishing a rule for HHW management system, practising source-separated collection system, and improving recycling activities.

Keyword: life cycle assessment, waste recycling, heavy metal contamination, municipal solid waste management, household hazardous waste, source-separated collection system.

1. INTRODUCTION

Household hazardous waste (HHW) contains substances potentially harmful to the environment and human health. The HHW are generally discarded alongside non-hazardous waste [1]. In many developing countries, municipal solid waste (MSW) is sent to landfill without separation and enough recycling efforts, therefore, HHW is predominantly disposed to landfills. Although HHW represents a small fraction of total MSW, accumulated HHW in landfill site causes problems to the environment.

National regulation UU No. 18/2008 classifies MSW in 3 categories: household waste from domestic source (SW1), household waste from non-domestic source (SW2) and specific waste (SW3). HHW is included in SW3. The management of SW1 and SW2 is regulated by PP No. 81/2012 and Permen PU No. 03/PRT/M/2013. As for national improvement in source-separated collection and recycling system for SW1 and SW2, some programs have been introduced as follows:

a) The Ministry of Environment issued a regulation Permen LH No. 13/2012 about reduce, reuse, and recycle through Solid Waste bank (SWB). It is a unique banking system where people deposit marketable wastes instead of money. SWB is a social engineering tool for building collective awareness in applying 3R concept in Indonesia. The detail of the system is explained elsewhere [2, 3, 4, 5].

b) 3R waste treatment facility (abbreviated as TPS 3R in Indonesian Language) is another community-based system introduced by the government for treating compostable waste at source scale (a group of 200–2,000 households). It is a place for waste collection, separation, reuse, and recycle. The facility must install separation room, composter or biogas reactor, and storage room with a total area of bigger than 200 m2. The operational of TPS 3R may be integrated with the SWB [6, 7].

c) Ministry of Public Works issued a regulation about integrated waste treatment facility (abbreviated as TPST in Indonesian Language) at municipality scale. TPST is a facility where the waste collection, reuse, recycle, and treatment take place. TPST may treat dry marketable and wet compostable waste. TPST may be established in downtown or at a landfill site. The facility has a total area of bigger than 20,000 m2 [7].

Meanwhile, regulation on SW3 management, especially for HHW, does not exist. Indonesia does not have a system for managing HHW from domestic and non-domestic sources, except for industrial hazardous waste [8].

Elanda *et al*. developed a model simulating environmental impacts due to the management of HHW. They reported that HHW recycle is the best option based on LCA study [8]. Aprilia *et al*. focus their study on inorganic and hazardous waste management in Indonesia, analysing the current situation and policies. They found that householders send the HHW together with general waste to temporary collection points due to the absence of separated formal collection and transportation [9]. Unfortunately, both papers did not discuss specific solutions for the problems.

Padang, the capital city of West Sumatera Province, is a big city with 11 districts and 104 villages. Padang has a population of around 868,066 people in 2013 [10]. It generated a total waste of around 587.67 tonnes per day in which 2.8% is HHW [11]. Around 60% of the total waste generation was transferred to Padang Municipal Landfill. However, recycling activities only accounted for 5.5 % of the total waste generation in 2013 [2]. In Padang, like most cities in Indonesia, people dispose of HHW such as fluorescent tubes and other mercury-containing waste, batteries and waste electronic and electronic equipment (WEEE) to general communal collection points. They are regularly transported to the municipal landfill.

A case of Padang MSWM was investigated in the current work. It evaluates the level of HHW contamination at the landfill site due to the current MSWM practices and proposes applicable solutions through improvement of the current recycling facilities and the inclusion of an HHW management system. LCA methodology based on environmental consideration was used to compare the current practice and 2 improved scenarios. 1 selected scenario would be proposed and discussed to the local government. Specific programs on developing the role of current 3R facilities and HHW management system were also discussed. These current findings may be useful for the national and local governments for establishing a new HHW management system.

2. METHODOLOGY

2.1 Current MSWM evaluation

In order to evaluate the current practices of local MSWM, field observations and interviews were carried out to the agency of city cleaning (Dinas Kebersihan dan Pertamanan, DKP), the city environmental bureau (Badan Pengendalian Dampak Lingkungan, Bapedalda), SWB, TPS 3R, TPST and scavengers. Currently, there are 47 SWBs, 4 TPS 3Rs and 2 TPSTs in Padang. 5 SWBs comprise of 3 communities, 1 university and 1 school SWBs were chosen for deep observation and interviews. Observation and interviews were also carried out to investigate 4 TPS 3Rs (TPS 3R Darul Ulum, TPS 3R Koto Lalang, TPS 3R Kami Saiyo, and TPS 3R KSM Jati Bergema), and 2 TPSTs (TPST DKP and TPST TPA Padang).

In this study, hazardous waste contamination was represented by the concentration of Mercury (Hg), Lead (Pb) and Cadmium (Cd) contained in leachate of Padang Municipal Landfill. They were investigated to understand the level of current heavy metal contamination in dry and rainy seasons 2015/2016. Cold-vapor atomic method was used for laboratory analysis of Hg concentration. Meanwhile, Indonesian National Standard (SNI) method SNI 6989.8:2009 and SNI 6989.16:2009 were used for Pb and Cd laboratory analysis, respectively. Finally, the measured concentration of Hg, Pb and Cd are compared with their national maximum limit as regulated by The Ministry of Environment Permen LH No. 5/2014.

2.2 Scenarios formulation for MSWM improvement

Identified weaknesses and problems in the current local MSWM were considered in formulating 2 (two) scenarios for MSWM improvement in the next 20 years. The first scenario was based on the following simulated conditions:

a) The implementation of national recycling programs SWB, TPS 3R and TPST is improved. The improvement will reduce the amount of MSW transferred to the landfill site.

b) The local city does not have HHW management.

The second scenario was simulated with the following ideas:

a) The implementation of national recycling programs SWB, TPS 3R and TPST is improved.

b) The local city applies HHW management system with gradual improvement.

2.3 Life cycle assessment

Originally, LCA is used in an industrial process to study the potential impacts to the environment throughout a product's life (i.e. cradle-to-grave) [12]. However, LCA methodology has been developed for a broader range of activities such as MSW management [13, 14, 15]. In this study, LCA was used for comparing environmental impacts due to the current practice of the local MSWM and 2 improved scenarios.

This LCA study was carried out using Integrated Solid Waste Management Model (ISWM) developed by The Corporations Supporting Recycling (CSR), Environment and Plastic Industry Council (EPIC), The City of London and Environment Canada. The model could be used for analysing and selecting various hypothetical waste recycling programs for project implementation [16].

ISWM can calculate the energy consumed and the emissions released from specified local MSWM. Indicator parameters of emissions include greenhouse gases, acid gases, smog precursor, heavy metals and organics. However, in this study, only the amount of

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heavy metals Hg, Pb and Cd are considered for the assessment of dangerous substances contamination to aquatic environment at a landfill site. Regarding the amount of heavy metals released at a municipal landfill site, ISWM assumes that the general MSW is contaminated by HHW. ISWM does not have a unit process for simulating HHW management. Therefore, a manual calculation must be added to the LCA results for a scenario with the application of HHW management. It is assumed that the current system of MSWM would transfer generated HHW to the municipal landfill and environment due to the absence of HHW management and the source-separated collection system. Meanwhile, the improved scenario with HHW management application would reduce the amount of HHW transferred to municipal landfill in accordance with the increased level of source-separated collection system for HHW. ISWM will calculate the remaining heavy metals Hg, Pb, and Cd release to the environment in accordance with the recycling process of units such as composting facility, MRF, etc. Boundary condition for the study is given in Figure-1.

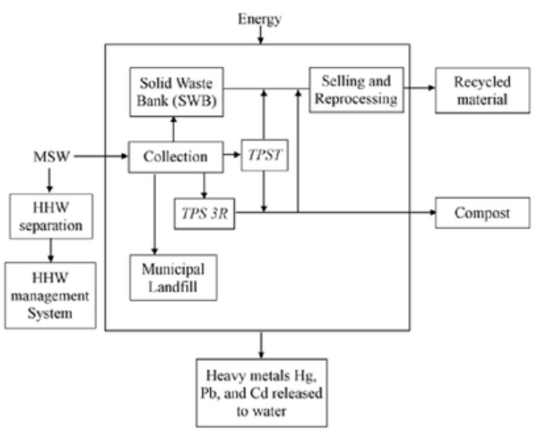

Figure-1. Boundary condition.

ISWM contains 12 main input data as follows: quantity and composition of waste; waste flow; waste collection, transfer and transportation; electric grid selection; recycling; materials recovery facility; composting; anaerobic digestion; land application; energy from waste; landfilling.

3. RESULT AND DISCUSSIONS

3.1 MSW generation and composition

MSW generation of Padang City is 0.67 kg/cap/day. It is used for predicting total waste generation in the next 20 years as given in Table-1. While, Table-2 displays the composition of MSW.

3.2 HHW contamination and the current MSWM practices

Table-3 compares the concentration of Hg, Pb and Cd in leachate outflow of Padang Municipal Landfill's leachate treatment plant with the national maximum limit. Table-3 reports that the current concentration of Hg, Pb and Cd exceeds the national maximum limit. It means that the heavy metals have been contaminating the environment. Observations show that SW1, SW2, and SW3 are found completely mixed at temporary collection points. Communities bring their MSW individually or MSW operators collect and bring waste collectively to temporary collection points. Arm-roll trucks and dump trucks operated by the local government transport the collected MSW from temporary collection points (abbreviated as TPS in Indonesian Language) to the municipal landfill. Unfortunately, there is no waste separation in transportation. Figure-2 illustrates the mixed waste at a temporary collection point.

Table-1. MSW generation for next 20 years in Padang city.

Year	Population	Waste generation (ton/year)
2015	877,128	214,502
2020	888,851	217,369
2025	897,359	219,449
2030	904,041	221,083
2035	909,544	222,429

Table-2. MSW composition in Padang City.

Category	Composition (weight %)
Food waste	32.92
Paper	13.21
Plastic	14.35
Textile	2.65
Rubber	1.18
Yard waste	1.23
Wood	20.67
Kulit	3.53
Total organic waste	89.69
Glass	1.33
Thin	1.81
Metals	1.58
Hazardous waste	2.87
Others	2.72
Total An-organic waste	10.31

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Table-3. Heavy metal concentrations.

Heavy metals	Concentration (mg/L)		National max. limit, grade II (mg/L)	Note
	Dry season	Rainy season		
Hg	0.039	0.023	0.005	Exceed
Pb	2.000	1.391	1.000	Exceed
Cd	0.161	0.105	0.100	Exceed

Figure-2. A temporary collection point (TPS) in Padang city.

In Padang City, the number of SWB has been increasing in the last two years by a double. Raharjo *et al*. reported that there were 29 SWBs with the average waste recycling of around 11 kg/day/SWB in 2013 [2]. Currently, there are 47 SWBs with the average waste recycling of around 23 kg/day/SWB. 5 observed SWBs accept marketable waste such as paper, plastic, metals, etc from the customers. However, the number of active customers varies from 10 to 150 people, which are only around 20% compared to the number of registered customers. SWBs do their business by reselling the deposited marketable waste to bigger recycle agents. The recycling achievement of SWBs is only 0.182% of the total generation of MSW in 2015.

Padang City has only 4 TPS 3Rs equipped with composting facilities which are currently inactive. Table-4 shows the technical data of each TPS 3R. Table-4 suggests that all TPS 3Rs may do composting. In fact, they only serve as transfer station without recycling activities. Hand rotary composters are not operated by the communities as illustrated in Figure-3. It is caused by the following reasons:

a) Local communities do not get involved in planning and construction of the facilities.

b) The establishment of the facilities is not followed with a sufficient community capacity building (CCB) for sustainable operation.

c) Lack operating cost.

Table-4. Facilities of TPS 3R.

No.	TPS 3R	Activities	Equipment (Unit)	Capacity	Status
1.	Darul Ulum	Composting, Plastic waste crushing	Hand rotary composter (5) Plastic crusher (1)	500 kg/unit 500 kg/unit	Inactive
2.	Koto Lalang	Composting	Hand rotary composter (5)	500 kg/unit	Inactive
3.	Jati Bergema	Composting	Hand rotary composter (5)	500 kg/unit	Inactive
4.	Kami Saiyo	Composting	Hand rotary composter (5)	500 kg/unit	Inactive

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Figure-3. A TPS 3R.

Padang City only has 2 TPSTs with limited capacity. TPST should handle MSW at municipality scale with a minimum capacity of 70 tonnes/day compostable waste. Table-5 below displays the technical data of TPST. The capacity of each facility is much lower than its standard.

Table-5. Facilities of TPST.

No	TPST	Activities	Equipment (Unit)	Capacity
1.	DKP	Composting	Composter (1)	32-35 kg/day
2.	TPA	Composting	Composter (1)	500 kg/day

HHW accounts for around 2.8 % of the total waste generation in Padang City. Interviews with the local government and field observations suggest that there is no HHW separation at sources. Figure-4 illustrates the current MSWM in Padang City. It does not practice source-separated collection and HHW management system which result in the mixed waste of SW1, SW2, and SW3. The people send the mixed waste to TPS and environment (river, land, etc), or even burning the waste. Finally, around 67 % of mixed waste will be sent to the municipal landfill. The achievement of recycling activities by TPS 3R, TPST and SWB is very low compared to the national standard. SW3 which contains HHW must contaminate the general waste so that the hazardous waste contaminates the landfill site. Considering other cities have similar current MSWM, HHW contamination to general waste may happen not only in Padang City but also all cities in Indonesia.

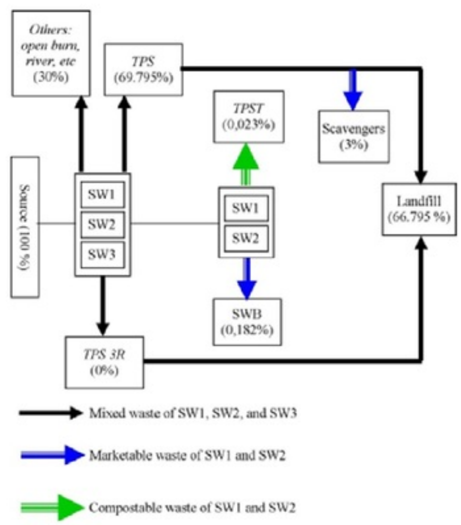

Figure-4. Current MSWM (2015) in Padang city.

3.3 Improved scenarios of MSWM

Indonesia has established national recycling programs through the implementation of SWB, TPS 3R, and TPST. However, observation on current MSWM suggests that the recycling achievement is only 3.205 % in

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2015 as displayed in Figure-4. Scenario #1 is given in Figure-5. It shows the idea to improve the recycling achievement of SWB, TPS 3R and TPST so that the amount of mixed waste (SW1, SW2 and SW3) transferred to a landfill would be reduced.

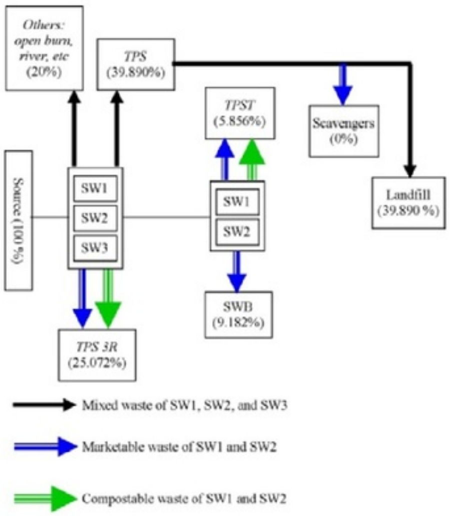

Figure-5. Improved scenario #1 (2035).

Figure-6 shows another idea of MSWM improvement. Apart from the improvement of recycling achievement of SWB, TPS 3R and TPST, gradual development of HHW management system is introduced into scenario #2. It rules that HHW of SW3 must be separated at sources and sent to a specific management. The gradual development of HHW management system would reduce HHW contamination to general waste (SW1 and SW2) which is sent to municipal landfill. Detail improvement plans of each facility in 20 years (2016-2035) are given in Table-6.

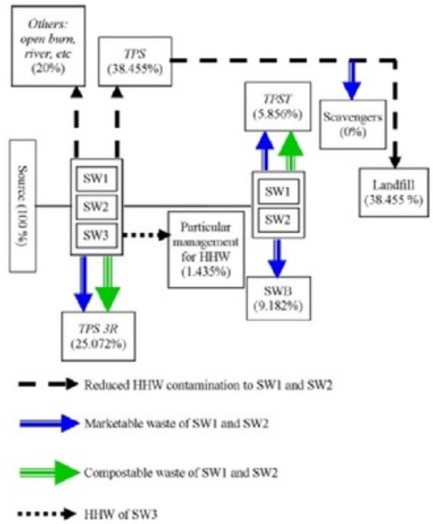

Figure-6. Improved scenario #2 (2035).

Table-6. Improvement plan of each scenario.

Item	Current	Skenario I	Skenario II
Waste recycling SWBefore landfill (% of total waste generation)	SWB: 0.182% (2015) 0.175% (2035) (marketable waste)	SWB: 1.232% (2020), 3.082% (2025), 5.732% (2030), and 9.182% (2035)	
	TPST DKP: 0,005% (2015) 0.004% (2035) (compostable waste)	TPST DKP: 0.164% (2020), 0.328% (2025), 0.492% (2030), and 0.656% (2035). (compostable waste)	
	TPS 3R : 0% (2015) 0% (2035) (compostable waste)	TPS 3R: 3.089% (2020), 6.400% (2025), 10.815% (2030), and 16.332% (2035). (compostable waste) TPS 3R: 1.653% (2020), 3.425% (2025), 5.788% (2030), and 8.740% (2035). (marketable waste)	
Waste recycling at landfill (% of total waste generation)	Scavengers: 0.018% (2015) 0.017% (2035) (marketable waste)	TPST TPA: 0.355% (2020), 0.591% (2025), 0.827% (2030), and 1.064% (2035) (compostable waste)	
	TPST TPA: 0.118% (2015) 0.114% (2035) (compostable waste)	TPST TPA: 2.363% (2020), 2.955% (2025), 3.545% (2030), and 4.136% (2035) (marketable waste). Scavengers are employed.	
HHW management (% of total HHW generation)	The local city does not have HHW management		The local city establishes HHW management with gradual improvement: 25% (2020), 35% (2025), 45% (2030), 55% (2035)

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Table-6 shows that waste recycling achievements (%) in scenario #1 and #2 are planned to increase through the implementation of SWB, TPS 3R, and TPST. Meanwhile, gradual improvement of HHW management system is simulated in scenario #2.

3.4 Life cycle assessment

Figure-7, 8 and 9 display the prediction of heavy metals (Hg, Pb, and Cd) discarded in the next 20 years (2016 - 2035) should the current system, improved scenario #1 and #2 be implemented. Comparison of the reduced heavy metals represented by Hg due to the implementation of each system is given in Table-7. Those simulation results suggest that the improvement of recycling activities through the improved implementation of national programs SWB, TPS 3R, and TPST in Padang City would reduce the heavy metals contamination at Padang Landfill site by 12.76 % in 2035. However, the gradual development of HHW management system would further reduce the contamination of the heavy metals by 60.74 % as simulated by scenario #2.

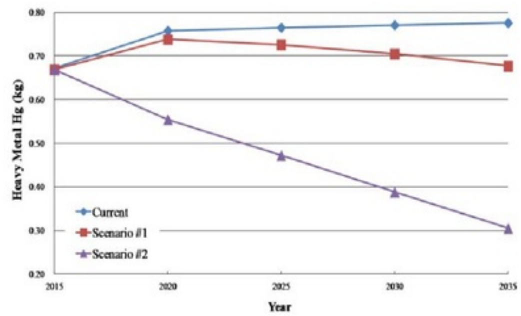

Figure-7. Result of LCA for heavy metal Hg.

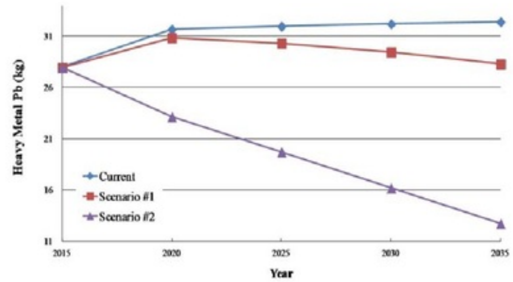

Figure-8. Result of LCA for heavy metal Pb.

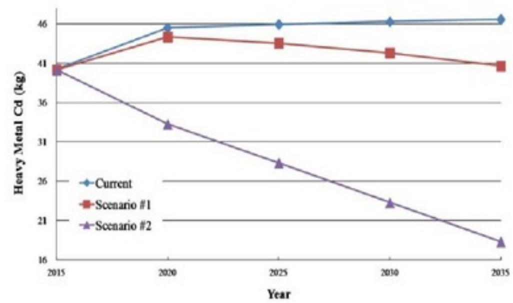

Figure-9. Result of LCA for heavy metal Cd.

Table-7. Reduced Hg for each system in 2035.

System	Amount of Hg discharged to environment 2035 (kg)	Reduced Hg (%)	
		C VS S1	C VS S2
Current (C)	0.776		
Scenario #I (S1)	0.677	12.76%	
Scenario #2 (S2)	0.305		60.74%

3.5 Scenario selection and recommendation

According to the LCA study, scenario #2 gives the highest amount of avoided heavy metal contamination to the landfill site. Discussion with the local government suggests that scenario #2 may be applied for local MSWM due to some reasons:

The local government has had a program to reduce the waste generation by 20 % in 2030.

The local government has a commitment to improving supervision on people participation in waste separation and recycling.

However, to implement scenario #2, the current practices and conditions must be changed as listed in Table-8.

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Table-8. Things must be changed for scenario #2 implementation.

Section	Current	Improvement
Regulation	National or local regulation on HHW management is not available	The government must issue regulations on HHW management
Source	Separation system between SW1, SW2, and SW3 is not established.	People must separate SW3 (HHW) from SW1 and SW2. MSW must be separated at least in four categories: marketable, compostable, HHW, and other wastes.
Recycling at source scale (200 – 2,000 household)	Limited recycling activities. Numbers of SWB and TPS 3R is still limited. SWB and TPS 3R do not have professional management.	It is necessary to build at least 1 SWB or TPS 3R in every village. SWB and TPS 3R must establish good management, operation and maintenance. Scavengers must involve in SWB or TPS 3R. SWB must improve its marketing strategy to get profit.
Collection and transportation at source scale	Waste separation system at temporary collection points/TPS is not established Waste separation system during transportation is not established. SWB and TPS 3R do not function as HHW collection points	People must send their marketable and compostable waste to SWB and TPS 3R. People must put their HHW (SW3) to HHW collection points such as SWB, TPS 3R or other community centers.
Recycling at municipality scale	Numbers of TPST is still limited. TPST does not function as HHW collection point.	Compostable waste from traditional market must be transferred to TPST. Compostable waste from source scale which is not handled by TPS 3R, may be sent to TPST. TPST may also establish municipality SWB for marketable waste handling. TPST must be functioned also as HHW collection point.
Collection and transportation at municipality scale	Waste separation system during collection and transportation at municipality scale is not established	HHW (SW3) must be separated from SW1 and SW2 Compostable waste must be sent to TPST. Marketable waste must be sent to municipality SWB. HHW (SW3) must be sent and kept at a secure place in TPST. HHW (SW3) collection and transportation may be done by a certified company.
HHW management	HHW management is not established	The local government must establish HHW management includes collection, transportation, temporary storage, treatment and landfilling. The local government may ask certified companies as a partner. SWB, TPS 3R and TPST may participate as HHW collection points. Transportation includes HHW transfer from HHW collection points (SWB, TPS 3R, TPST, community centers) to municipality HHW temporary storage room at Padang Municipal Landfill.
Padang municipal Landfill.	Controlled landfill operation HHW temporary storage rooms/facilities are not available	The operation must be upgraded to a sanitary landfill. The landfill must build rooms/facilities for Municipality HHW temporary storage. Collected HHW is regularly sent to certified HHW treatment facilities/company. The coverage service of HHW management must be gradually developed so that HHW entering the landfill can be minimized.

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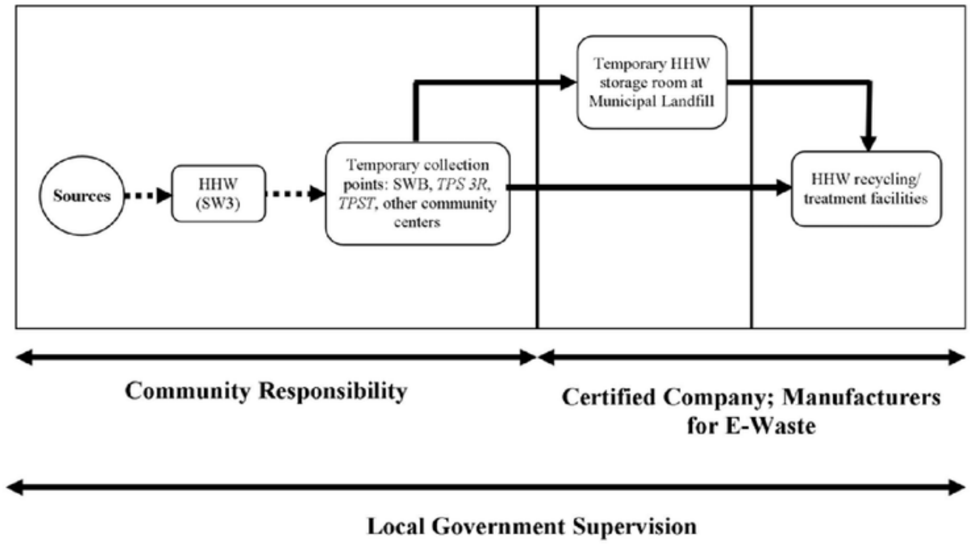

Figure-10. Framework of HHW management system.

Considering the reduced contamination of the heavy metals by 60.74 % as suggested by scenario #2, all cities in Indonesia including Padang must establish HHW management system. The framework of HHW management system is proposed in Figure-10. It illustrates that the communities must sort the HHW from general waste (SW1 and SW2) and send it to HHW temporary collection points. SWB, TPS 3R and TPST must be functioned as dropping point for HHW including electronic waste (e-waste). The local government must establish cooperation with companies that hold certification for hazardous waste management. The companies have responsibility for HHW transportation and recycling/treatment. Especially for e-waste, the manufacturers must collect their electronic product through extended producer responsibility (EPR) program. The main responsibility of the local government is to implement coordination and supervision for the whole process.

4. CONCLUSIONS

Current concentration of Hg, Pb and Cd in outflow of the leach ate treatment facility of the landfill site exceeds the national maximum limit. It means that the heavy metals have been contaminating the environment as a result of the current MSWM in Padang City.

The current MSWM in Padang City does not practice source-separated waste during collection and transportation. HHW management system does not exist as a part of the local MSWM. In addition, the achievement of recycling activities is also relatively low compared to the national standard. Those conditions result in HHW-contaminated waste which is sent to the municipal landfill. Considering the other cities have similar current MSWM, HHW contamination to general waste may happen not only in Padang City, But also all cities in Indonesia.

LCA study suggests that the improvement of recycling activities through the implementation of national programs SWB, TPS 3R, and TPST in Padang City would reduce the heavy metals contamination at Padang Landfill site by 12.76 % in 2035. However, the gradual development of particular HHW management would further reduce the contamination of the heavy metals by 60.74 % as suggested by scenario #2. Improvement of recycling achievement and gradual development of HHW management would reduce HHW contamination to general waste (SW1 and SW2) which is sent to municipal landfill.

To implement the scenario #2, some important conditions must be changed and improved such as introducing national and local regulation on HHW management system, establishing source-separated collection for HHW, implementing SWB, TPS 3R, TPST, and other community centers as collection points for HHW, establishing cooperation with certified third-party company for HHW transportation and treatment, etc. Furthermore, communities and private sectors (certified hazardous waste management companies and electronic manufacturers) must be coordinated and supervised by the local government in implementing gradual HHW management system.

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