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Environmental Impact, Health Risk, and Management Cost of Landfilling Practice: A Case Study in Klang, Selangor, Malaysia

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Abstract

Introduction: Selangor is known as the main waste contributor in Malaysia. The state generates 7,220 tons of solid waste a day. Around 80-90% of waste is disposed of in landfills that lead to environmental and human health problems as well as high management costs.

Objective: This study aims to analyze the environmental impact, health risk and waste management costs of landfilling practice in Klang, Selangor.

Methods: In this study, the Intergovernmental Panel on Climate Change (IPCC) methods was used to estimate the GHG emission. Air Pollutant Emission Factors (AP-42,Vol.1, 1998), and Emission Estimation Technique Manual for MSW Landfills (Version 2.0, 2010) were used to analyze non-methane organic compounds (NMOC) and heavy metals, respectively. The method from Gerard, 1998 was used to estimate the landfill area for waste disposal. For health risk assessment, the equations were obtained from U.S EPA. Mathematical equations for leachate and management costs were adopted and modified from Solid Waste Management Lab 2015.

Results: In average Klang generates 199,593.48 tons/year (t/yr.) of solid waste. In total of 7 years, CH_4 emission was 60,588.04 tons (mean ±SD = 8,655.43 tons / year (t/yr.) ±697.93 t) that equivalent to 1,514,700.97 tons of CO_2-eq emission (mean ±SD = 216,385.85 t/yr. ±17,448.19 t). Leachate production and land use were 41,914.63 m^3/yr. ±3,379.77 and 2.38 ha/year (ha/yr.) ±0.19 ha). Heavy metals were 35% Pb, 35% Zn, 14% Cr, 12% Cu and 4% Cd. The highest NMOC emission was hydrogen sulfide (2.35E-01 m^3/yr.). There was an acceptable risk for carcinogenic and non-carcinogenic exposure to the NMOC. Collection and transportation were the highest costs (67%) of waste management.

Conclusion: Poor landfilling practice can cause high impacts to the environment, health and cost where other sustainable approaches of MSW management should be considered in a future study.

Keywords: Landfilling Management Cost; Waste Generation; Landfilling Environmental Impact; Klang-Selangor Landfilling Practice; Klang Solid Waste

Introduction

At present, the global solid waste generation is 1.3 billion tons per year (t/yr.) and is estimated to increase up to 2.2 billion t/yr. in 2025 [1]. Among the ASEAN countries, Indonesia generates the highest amount of waste annually (64,000,000 million t/yr.), followed by Thailand (26,770,000 million t/yr.), Vietnam (22,020,000 million t/yr.), Philippines (14,660,000 million t/yr.) and Malaysia (12,840,000 million t/yr.) [2].

Waste generation in Malaysia is expected to increase up to 18.13 million t/yr. with the estimated total population of 33.34 million by 2020 [3,4]. About 65% of Malaysians' municipal solid waste (MSW) comes from households and the remaining 28% and 7% come from institutionalization and commercialization, and industrialization, respectively. Food waste is the highest waste produced by households (44.5%) and the institution, commercial, and the industry produces 31.4% of food waste. Household generates 13.2% of plastic waste that is less compared to the institution, commercial, and the industry (25.9% of plastic). Diapers (12.1%) and paper (20.5%) are the third highest amount of waste that come from households and the institution, commercial, and the industry, respectively [5].

Selangor has the largest population distribution in Malaysia, which is 5.46 million (census in 2010), making the state as the main waste generator in the country [6]. Based on the previous data in 2014, Selangor generates 6,855.11 (19%) t/day of solid waste. This is followed by Johor (4,205.97 t/day or 12%) and Sabah (4,030.20 t/day or 11%) [7]. Currently, waste generated by Selangor has increased to 7,220 t/day (22%), followed by Johor (4,470 t/day or 13%). The lowest waste contributor is Perlis (600 t/day or 2%) [8].

In Selangor, Klang is one of the areas that have the largest total population under the jurisdiction of the Klang Municipal Council, which is 757,965 (13.88%) based on the 2010 Malaysian census. Waste generation in Klang is 1.35 kg/capita/day or, in totals 1,023 million t/day [5]. The waste recycling rate in the area is still low at 9.4%, which means that around 90% of the generated waste is disposed of in landfills [5]. The solid waste and public cleansing management (SWPCM) in Klang is managed by the Klang Municipal Council with the enforcement of the Local Government Act 1976 (Act 171), Street, Drainage and Building Act 1974 (Act 133), and Town and Country Planning Act 1976 (Act 172).

Conventionally, the hierarchy of waste management is often used in waste management strategies that give the order of preference, in which the best option is waste minimization (reduction). The second option is re-using, followed by recycling, composting, and thermal treatment (with energy recovery and without energy recovery) [9]. The last option of the hierarchy is landfilling as this method leads to a lot of environmental problems and human health risks [10].

However, landfilling is still the most preferable method of waste disposal in developing countries such as Malaysia, in which 80 to 90% of waste is disposed of in landfills. This method has a low cost in operation and maintenance [11-13]. Currently, the country has 158 operating landfills and 144 closed landfills. Selangor itself has 8 operating landfills, consisting of 3 inert landfills, 3 sanitary landfills and 2 non-sanitary landfills [14].

MSW management is the third major environmental problem in Malaysia after water and air pollution [10]. For example, poor management of landfilling practice leads to a lot of environmental problems and health impacts. According to the Intergovernmental Panel on Climate Change (IPCC), landfills contribute 5% to the total global GHG emission that potentially causes climate change and global warming [15]. Besides that, pollutants from landfills cause environmental pollution such as air pollution, soil and water [16,17]. Living near to landfills is also linked to various diseases such as cancer, respiratory problems, reproductive outcomes and other diseases as nearby residents are exposed to non-carcinogenic and carcinogenic pollutants (e.g. non-methane organic compounds [NMOC]) [18].

In terms of economic feasibility, building up a new landfill in Malaysia requires more than 7.75 million USD and to date, the government has spent approximately 5.24 billion USD every year for the management of solid waste in the country with the cost for waste collection and disposal alone taking up to 60% of local authority expenditure [19-21].

This study presents the trend of waste generation in Klang, Selangor from 2011 to 2017. The study aims to analyze the environmental impact (i.e. CO_2, CH_4, NMOC emission, heavy metals, leachate production, and land use), and health risk (exposure to NMOC) of the landfilling method that is practiced by the study area. It also aims to analyze the waste management costs (i.e. collection and transportation, leachate treatment, land use, and landfill tipping fees) in the study area. The volume of total disposed solid waste was used to analyze its impact (i.e. environment and health risk) using mathematical equations.

The findings in this study are expected to provide relevant information to the government or stakeholders in planning waste management strategies for the country, especially for the Klang area. Besides that, the findings can also support the need for developing a sustainable approach of solid waste management in Malaysia such as integrated solid waste management that is environmentally efficient, economically affordable, and socially acceptable.

Methodology

Study Design

This study utilized a cross-sectional study design. The data were collected at a particular point in time.

Study Location

The study chose Klang, Selangor (Malaysia) as the study area since it is the major waste generator in the country at 1.35 kg/capita/day or 9,702 metric tons/day of solid waste [5] (Figure 1). The total population of this area was 861,189 based on the 2010 census (changed +2.36% every year) with an area of 672km^2 and the density of 1,374/km^2. Basically, waste management in Klang involves waste collection, transportation, and disposal (i.e. landfills). Waste collection is scheduled three times per week for domestic or households waste, and 12 to 36 times in a month for garden and illegal waste. The collected waste is disposed of in the Jeram sanitary landfill [22].

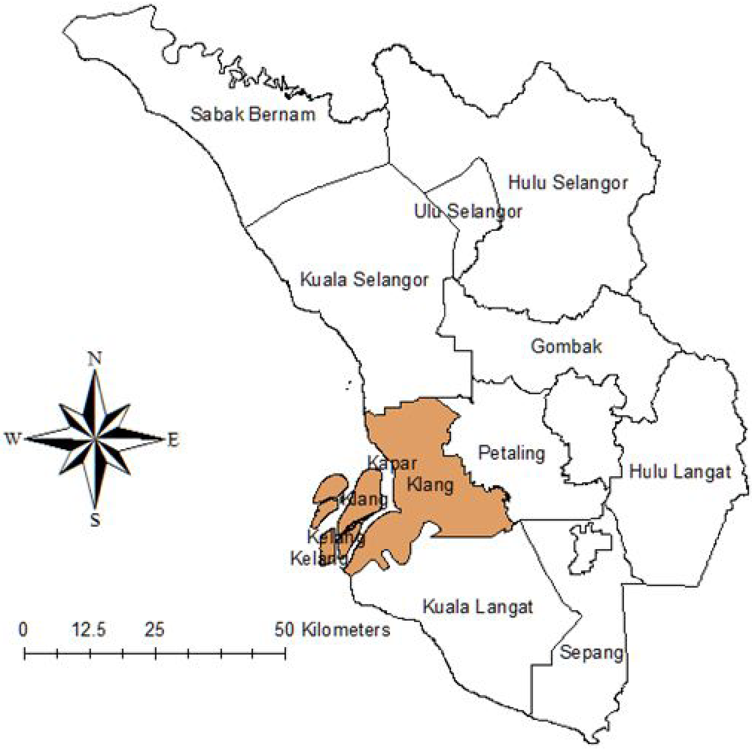


Figure 1: Selangor state and Klang was highlighted in the map as the study area

Data collection

The secondary data set of solid waste volume was obtained from the Klang Municipal Council. The available data from the Klang Municipal Council was only the total volume of disposed of solid waste in the landfill (Jeram sanitary landfill) from 2011 to 2017 that was used to analyze its potential impact on the environment, health, and management costs using the recommended mathematical equations.

Data Analysis

The data were analyzed using the SPSS software (Statistical Package for Social Sciences) to obtain the total, minimum (min) and maximum value (max), mean, and standard deviation (±SD) of the data.

Mathematical Equations

The mathematical equations used in this study are shown in Table 1. Greenhouse gases (GHG) emission (i.e. CH_4, CO_2) were analyzed using the recommended method from The Intergovernmental Panel on Climate Change (IPCC, 2006) [23]. Non-methane organic compounds emission was analyzed using the equation method of Air Pollutant Emission Factors (AP-42, Vol.1, 1998) [24].

For the heavy metals estimations, the method was adopted from Emission Estimation Technique Manual for Municipal Solid Waste (MSW) Landfills Version 2.0, 2010 from Department of the Environment, Water, Heritage and the Arts of Australian Government (National Pollutant Inventory [NPI], 2010) [25]. The recommended method from Gerard, 1998 was used to estimate the landfill area for waste disposal [26].

	Parameter	Equation
a)	Methane emission (CH_4) [23]	$\mathbf{TCH_4} = \sum\left[(MSWT \times MSWF \times MCF \times DOC \times DOCF \times F) \times \frac{16}{12}\right]$ ---- (1) **TCH_4** = Total CH_4 emission (tonne). **MSWT** = Volume of MSW disposed of in landfills (tonne). **MSWF** = Municipal solid waste fraction (MSWF) is 0.8 as Malaysia disposed 80% of waste in landfills [11]. **MCF** = Methane correction factors (MCF) is range from 0.4-1.0, value 0.6 can be used for Malaysia landfill [31]. **DOC** = Degradable organic carbon (DOC) was 0.16 (calculated in this study). **DOC** = degradable organic carbon fraction (DOCF) of 0.77 was used [31]. **F** = Fraction (F) refers to methane fraction which is 0.55 value was used as the global estimation of CH_4 emission from landfills is 5% [1]. **16/12** = The conversion of carbon (C) to CH_4 [23]
b)	Carbon dioxide equivalent (CO_2-eq) [23]	$\mathbf{TCO_2-eq} = \sum[TCH4 \times 25]$---(**2**) **$TCO_2$-eq** = Total carbon dioxide equivalent (TCO_2-eq) (tonne). **25** = It defined as 100-year global warming potential (GWP) factors by multiplying the estimated total CH_4 emission (TCH_4) (Equation 1) by 25 as CH_4 has 25 times GWP than CO_2 [23].

	Parameter	Equation
c)	Non-methane organic compounds (NMOC) emission [24]	$$\text{NMOC} = \sum_{P} [1.82 \times TCH4 \times \left(\frac{CP}{10^6}\right)] --- (3)$$ **NMOC** = non-methane organic compounds (NMOCs) emission (m^3) **P** = The P refers to the type of NMOC. **1.82** = the multiplication factor of 1.82 was used as 55% CH_4 and 45% CO_2 produced in a landfill. **TCH_4** = The total volume of CH_4 emission estimated from Eq. 1. (Conversion to m^3: 1 tonne = 0.42m^3). **CP** = The concentration of compound P. The default value of compound P concentration (unit: ppmv) as follow; (Acrylonitrile=6.33; Carbon disulfide=0.58; Carbon tetrachloride=0.004; Carbonyl sulfide=0.49; Chlorobenzene=0.25; Chloroethane=1.25; Chloroform=0.03; Dichlorobenzene=0.21; Dichloromethane=14.3; Ethylbenzene=4.61; Hydrogen sulfide=35.5) [24]. **1 x 106** = the conversion of ppmv to m^3
d)	Leachate production [3]	$$\text{VL} = \sum [MSWT \times 0.21] --- (4)$$ **VL** = volume of leachate (VL) discharge (m^3). **MSWT** = Total municipal solid waste disposed in the landfill (tonne). **0.21** = refers to one tonne of waste generates 0.21m^3 of leachate [3].
e)	Heavy metals [25]	$$\text{HQ} = \sum_{h} [VL \times Ch] --- (5)$$ **HQ** = total of heavy metals quantity released in kg per year (kg-year). **h** = refers to the type of heavy metals (i.e. Cadmium, Cd; Chromium, Cr; Copper, Cu; Lead, Pb; Zinc, Zn). **VL** = total volume of leachate (VL) produced (m^3), estimated from equation (4). **C** = the average of heavy metals concentration (kg-m^3) in landfill leachate based on a case study in Malaysia (Cd = 2.00E-06; Cr = 6.00E-06; Cu = 5.00E-06; Pb = 1.50E-05; Zn = 1.50E-05) [38].
f)	Land use [26]	$$\text{LFS} = \sum [(MSWT / Density\ of\ waste)] --- (6)$$ **LFS** = landfill space (LFS) required annually in cubic meter per year (m^3/year) **MSWT** = Total municipal solid waste disposed in the landfill (tonne). Density of waste = 0.7 tonne per cubic meter (t-m^3) $$\text{RLA} = \sum [(LFS / Landfill\ height) / 1000)] --- (7)$$ **RLA** = Required land area (RLA) (ha). **LFS** = The estimated landfill space from equation (6). **Landfill height** = standard height of landfill (12 meter) **10 000** = the conversion of m2 to hectare (ha).
g)	Health risk [27]	$$\text{EHE} = \sum_{i} [(Ci \times IR \times EF \times ED) / (BW \times AT) --- (8)$$ EHE = Inhalation exposure to pollutant P (m^3/kg/year) **i** = type of pollutant P (NMOC), Ci= the concentration of type i pollutant P emission; estimated from equation (3). **IR** = inhalation rate (IR). (15m^3/day-child; 23m^3/day-Adult man; 21m^3/day-Adult woman [39]. EF = The exposure frequency (EF) is 1 year (365 days). **ED** = The exposure duration (ED) is based on the landfill lifespan which is 20 years [3]. **BW** = The average body weight (BW) (Child: 31.8 kg [39]; Adult man: 66.56kg; and Adult woman 58.44 [40]. **AT** = The averaging time (AT) for carcinogenic effects is equal to the ED, while for carcinogenic effects, the AT is 72.7 year for male, and 77.6 year for female [6]. Thus, The life time cancer risk (LCR) for carcinogenic risk was calculated using equation (9); $$\text{LCR} = \sum_{i} (EHE \times URF) --- (9)$$ **LCR** = life time cancer risk for carcinogenic risk. **i** = type of pollutant P (NMOC). **EHE** = Inhalation exposure to pollutant P (m^3/kg/year). **URF** = unit risk factor (URF) for carcinogenic was obtained from the Integrated Risk Information System (IRIS), US EPA. The chronic health risk (HQ) for non-carcinogenic risk was calculated using equation (10); $$\text{Hazard Quotient (HQ)} = \sum_{i} EHE / Rfc --- (10)$$ **HQ** = The hazard quotient for non-carcinogenic risk. i = type of pollutant P (NMOC). **EHE** = Inhalation exposure to pollutant P (m^3/kg/year). **Rfc** = The inhalation reference dose (Rfc) for non-carcinogenic risk was obtained from the IRIS, US EPA.
h)	Management cost, Malaysia Ringgit, MYR(US Dollar, USD) [3]	**Collection and transportation cost:** **CTC** = Σ[(MSWT ×CP)+(MSWT×TrP)] ---(11) **CTC** = Total estimated cost for waste collection and transportation. **MSWT** = Total municipal solid waste disposed in the landfill (tonne). **CP** = Waste collection cost (1 tonne of waste = 66MYR (15.99USD) per day) [3]. **TrP** = Transportation cost (1 tonne of waste = 40MYR (9.69USD) per day) [3].

	Parameter	Equation
h)	Management cost, Malaysia Ringgit, MYR(US Dollar, USD) [3]	**Leachate treatment cost:** **LTC = Σ[LP×TP] ---(12)** **LTC** = Total estimated cost for leachate treatment (RM). **LP** = volume of leachate produced (LP), equation (4). **TP** = Treatment price (TP) is 35MYR (8.48USD) per m^3 of leachate volume [3] **Land use cost:** **LUC = Σ[RLA×LP] ---(13)** **LCU** = Total estimated cost for land use (RM). **RLA** = Required land area (RLA) (ha), equation (7). **LP** = Land price (LP) is 250,000MYR (60,573.25USD) per hectare (ha) of land use [3]. **Landfill tipping fee** **TF** = Σ[MSWT×TFP] ---(14) **TF** = Tipping fee (TF) for waste disposal in a landfill. **MSWT** = Total municipal solid waste (MSWT) disposed in the landfill (tonne). **TFP** = The price for tipping fee (TFP) in Malaysia is 42MYR (10.18USD) per tonne of waste [3].

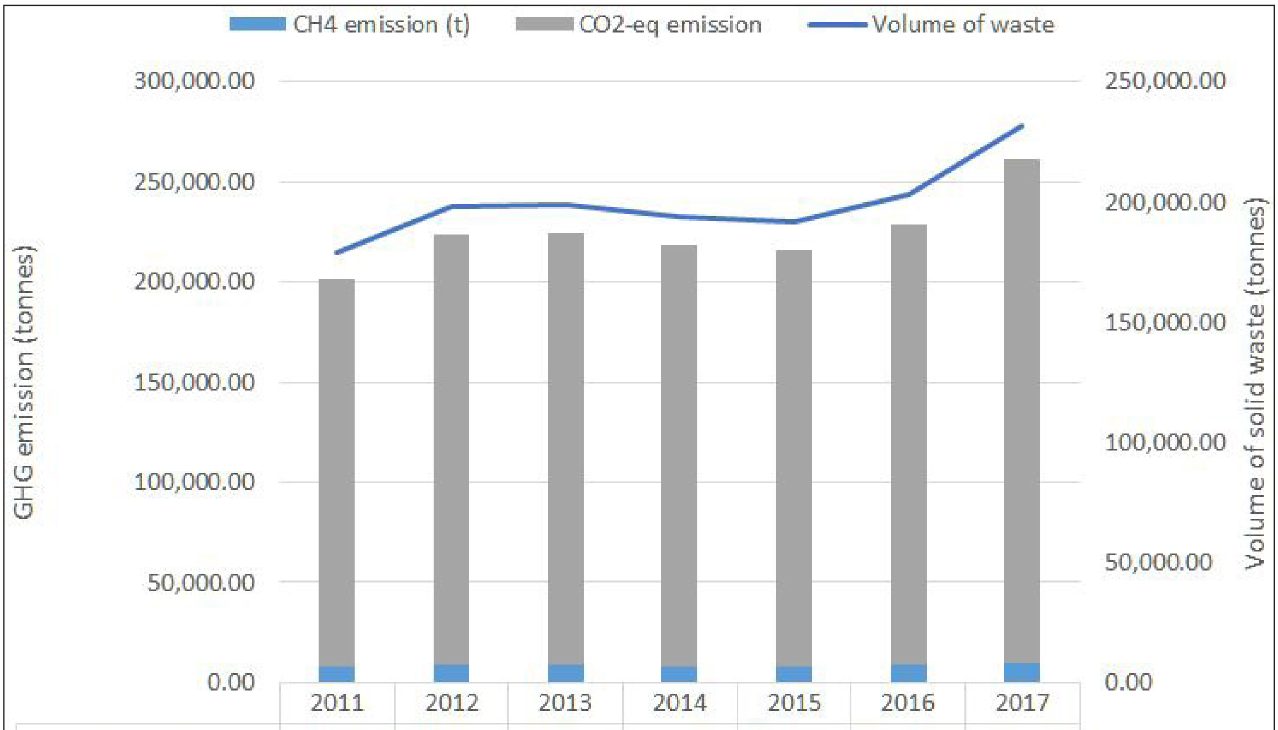
Table 1: The mathematical equations used in the study

The health risk equation methods from U.S Environmental Protection Agency were used to identify the risk (carcinogenic and non-carcinogenic risk) exposure to the landfill pollutants (i.e. NMOC) [27]. For leachate production and waste management costs (i.e. collection, transportation, leachate treatment, land use, and landfill tipping fees), the equation methods were adopted and modified from Solid Waste Management Lab 2015 [3].

Results

Solid waste generation in Klang

In the total of 7 years (2011-2017), Klang disposed of 1,397,154.34 tons (t) of solid waste with the average of 199,593.48 tons/year (t/yr.) in the landfill (Jeram landfill). Waste generation in Klang increased from 12.81% (178,953.56 t) in 2011 to 16.58% (231,605.63 t) in 2017 (Figure 2).



	2011	2012	2013	2014	2015	2016	2017
CO2-eq emission	194,009.4	215,060.2	215,888.6	210,515.8	207,974.4	220,161.0	251,091.2
CH4 emission (t)	7,760.38	8,602.41	8,635.55	8,420.63	8,318.98	8,806.44	10,043.65
Volume of waste	178,953.5	198,370.7	199,134.8	194,179.0	191,834.8	203,075.7	231,605.6

Figure 2: The trend of solid waste generation in Klang and emission of GHG in the landfill

Estimation of GHG emission in landfill

Table 2 shows the descriptive analysis of potential environmental impact through landfilling practice (i.e. waste disposal in the landfill) in Klang. The emission of methane (CH_4) and carbon dioxide equivalent (CO_2-eq) were estimated based on the total volume of solid waste disposed of in the landfill from 2011 to 2017. In total of 7 years, the estimated emission of methane (CH_4) was 60,588.04 tons of CH_4 (mean ±SD = 8,655.43 tons / year (t/yr.) ±697.93 t) that equivalent to 1,514,700.97 tons of CO_2-eq emission (mean ±SD = 216,385.85 t/yr. ±17,448.19 t). As shown in Figure 2, the GHG emission (2011-2017) increased as the volume of solid waste disposed of in the landfill increased. The CH_4 emission increased from 7,760.38 t (equivalent to 194,009.44 t of CO_2-eq) in 2011 to 10,043.65 t (equivalent to 251,091.28 t of CO_2) in 2017.

Result	Year							Statistic				
	2011	2012	2013	2014	2015	2016	2017	Total	Min	Max	Mean	±SD
Environmental impact												
CH_4 emission (t)	7,760.38	8,602.41	8,635.55	8,420.63	8,318.98	8,806.44	10,043.65	60,588.04	7,760.38	10,043.65	8,655.43	697.93
CO_2-eq emission (t)	194,009.44	215,060.21	215,888.64	210,515.84	207,974.47	220,161.09	251,091.28	1,514,700.97	194,009.44	251,091.28	216,385.85	17,448.19
Leachate (m^3)	37,580.25	41,657.85	41,818.32	40,777.59	40,285.32	42,645.91	48,637.18	293,402.42	37,580.25	48,637.18	41,914.63	3,379.77
Land use (ha)	2.13	2.36	2.37	2.31	2.28	2.42	2.76	16.63	2.13	2.76	2.38	0.19
Heavy metals (kg)												
Cadmium (Cd)	0.08	0.08	0.08	0.08	0.08	0.09	0.10	0.59	0.08	0.10	0.08	0.007
Chromium (Cr)	0.23	0.25	0.25	0.23	0.24	0.26	0.29	1.76	0.23	0.29	0.25	0.02
Copper (Cu)	0.19	0.21	0.21	0.20	0.20	0.21	0.24	1.47	0.19	0.24	0.21	0.02
Lead (Pb)	0.56	0.63	0.63	0.61	0.60	0.64	0.73	4.40	0.56	0.73	0.63	0.05
Zinc (Zn)	0.56	0.63	0.63	0.61	0.60	0.64	0.73	4.40	0.56	0.73	0.63	0.05
NMOC emission (m^3)												
Acrylonitrile	3.75E-02	4.16E-02	4.18E-02	4.07E-02	4.03E-02	4.26E-02	4.86E-02	2.93E-01	3.75E-02	4.86E-02	4.19E-02	3.39E-03
Carbon disulfide	3.44E-03	3.82E-03	3.83E-03	3.73E-03	3.69E-03	3.91E-03	4.45E-03	2.68E-02	3.44E-03	4.45E-03	3.84E-03	3.09E-04
Carbon tetrachloride	2.37E-05	2.63E-05	2.64E-05	2.57E-05	2.54E-05	2.69E-05	3.07E-05	1.85E-04	2.37E-05	3.07E-05	2.64E-05	2.14E-06
Carbonyl sulfide	2.90E-03	3.22E-03	3.23E-03	3.16E-03	3.11E-03	3.30E-03	3.76E-03	2.27E-02	2.90E-03	3.76E-03	3.24E-03	2.62E-04
Chlorobenzene	1.48E-03	1.65E-03	1.66E-03	1.61E-03	1.59E-03	1.68E-03	1.92E-03	1.16E-02	1.48E-03	1.92E-03	1.66E-03	1.34E-04
Chloroethane	7.42E-03	8.22E-03	8.26E-03	8.05E-03	7.95E-03	8.41E-03	9.59E-03	5.79E-02	7.42E-03	9.59E-03	8.27E-03	6.63E-04
Chloroform	1.78E-04	1.98E-04	1.98E-04	1.93E-04	1.91E-04	2.02E-04	2.31E-04	1.39E-03	1.78E-04	2.31E-04	1.99E-04	1.62E-05
Dichloromethane	8.49E-02	9.40E-02	9.44E-02	9.21E-02	9.10E-02	9.63E-02	1.10E-01	6.62E-01	8.49E-02	1.10E-01	9.47E-02	7.68E-03
Ethylbenzene	2.74E-02	3.04E-02	3.05E-02	2.97E-02	2.94E-02	3.10E-02	3.54E-02	2.14E-01	2.74E-02	3.54E-02	3.05E-02	2.44E-03
Hydrogen Sulfide	2.11E-01	2.33E-01	2.34E-01	2.29E-01	2.26E-01	2.40E-01	2.73E-01	1.65E+00	2.11E-01	2.73E-01	2.35E-01	1.90E-02

Table 2: The environmental impacts of current practice (landfilling) of solid waste management in Klang, Selangor

Leachate production and heavy metals

Waste disposal in the landfill produced 293,402.42 cubic meter (m^3) (mean ±SD = 41,914.63 cubic meter / year (m^3/yr.) ±3,379.77 m^3) of leachate. Leachate production increased from 34,047.71 m^3 in 2011 to 44,065.29 m^3 in 2017 (Table 2). This production leads to leachate containing heavy metals. Therefore, the study estimated the volume (in kg) of heavy metals (i.e. cadmium, chromium, copper, lead, and zinc) in landfill leachate based on the estimated volume of leachate produced.

The study reported (Table 2) that leachate contained high volume of lead (Pb), 4.40 kg or 35% (mean ±SD= 0.63 kg/yr. ±0.05 kg) and zinc (Zn), 4.40 kg or 35% (mean ±SD= 0.63 kg/yr. ±0.05 kg) followed by chromium (Cr), 1.76 kg or 14% (mean ±SD= 0.25 kg/yr. ±0.02 kg); copper (Cu), 1.47 kg or 12% (mean ±SD= 0.21 kg/yr. ±0.02 kg) and cadmium (Cd), 0.59 kg or 4% (mean ±SD= 0.08 kg/yr. ±0.01 kg).

Land use

As shown in Table 2, waste disposal (from 2011 to 2017) in the landfill by Klang used landfill space area around 16.63 hectares (ha) (mean ±SD = 2.38 ha/year (ha/yr.) ±0.19 ha). Increased use of landfill space was parallel with the volume of solid waste disposed of in the landfill. Land use increased from 2.13 ha in 2011 to 2.76 ha in 2017.

NMOC emission

The landfill gas constituents or non-methane organic compounds (NMOC) was estimated based on the estimated volume of methane ($CH_{4)}$ emission in this study (Table 2). The estimated volume for each NMOC emission with the average (mean ±SD) was acrylonitrile (4.19E-02 m^3/yr. ±3.39E-03 m^3), carbon disulfide (3.84E-03 m^3/yr. ±3.09E-04 m^3), carbon tetrachloride (2.64E-05 m^3/yr. ±2.14E-06 m^3), carbonyl sulfide (3.24E-03 m^3/yr. ±2.62E-04 m^3), chlorobenzene (1.66E-03 m^3/yr. ±1.34E-04 m^3), chloroethane (8.27E-03 m^3/yr. ±6.63E-04 m^3), chloroform (1.99E-04 m^3/yr. ±1.62E-05 m^3), dichloromethane (9.47E-02 m^3/yr. ±7.68E-03 m^3), ethylbenzene (3.05E-02 m^3/yr. ±2.44E-03 m^3). For hydrogen sulfide, the average total emission was 2.35E-01 m^3/yr. ±1.90E-02m^3).

Figure 3 shows that the highest NMOC emission (average) was hydrogen sulfide (2.35E-01 m^3/yr.) followed by dichloromethane (9.47E-02 m^3/yr.), acrylonitrile (4.19E-02 m^3/yr.), ethylbenzene (3.05E-02 m^3/yr.), chloroethane (8.27E-03 m^3/yr.), carbon disulfide (3.84E-03 m^3/yr.), carbonyl sulfide (3.24E-03 m^3/yr.), chlorobenzene (1.66E-03 m^3/yr.), chloroform (1.99E-04 m^3/yr.), and carbon tetrachloride (2.64E-05 m^3/yr.).

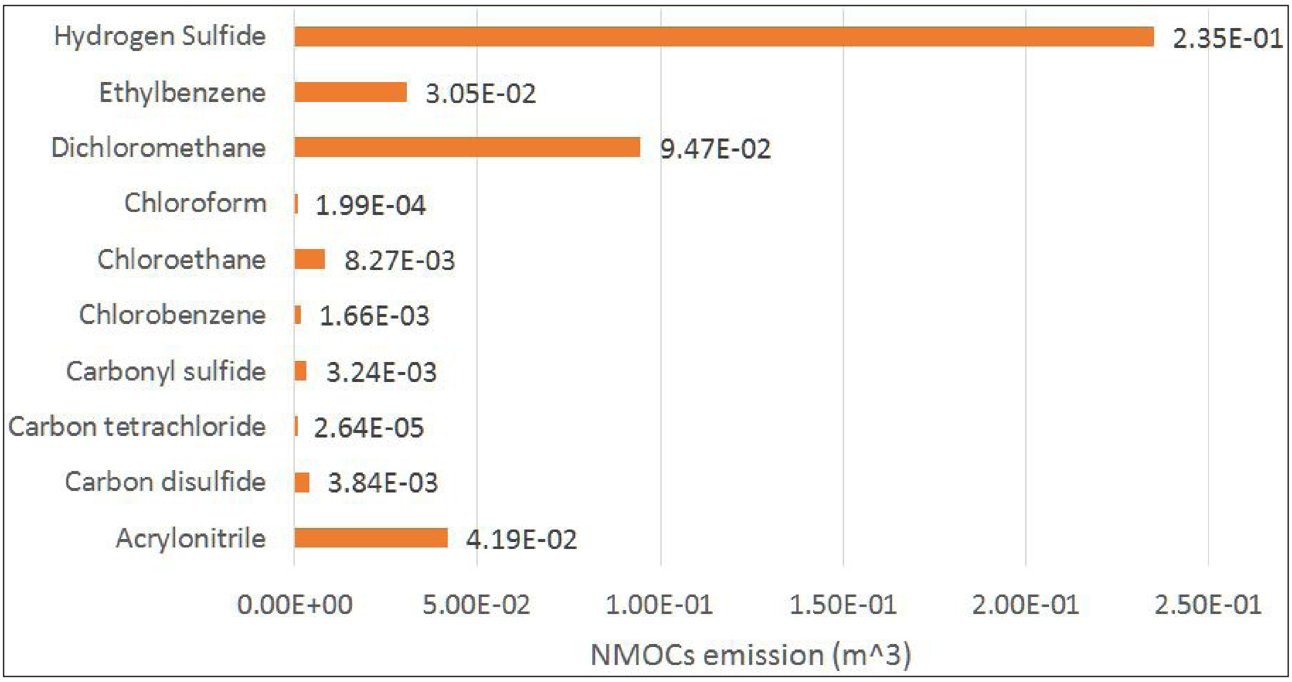


Figure 3: The average (mean) of NMOCs emission (2011-2017)

Health Risk (inhalation exposure)

Table 3 shows the result of inhalation exposure analysis for three groups which is child, adult man, and adult woman. There was the acceptable risk for non-carcinogenic effect of acrylonitrile (child Hazard quotient for non-carcinogenic risk (HQ) = 1.42E-08; man HQ = 1.04E-08; woman HQ = 1.09E-08), carbon disulfide (child HQ = 4.57E-07; man HQ = 3.35E-07; woman HQ = 3.48E-07), carbon tetrachloride (child HQ = 4.50E-10; man HQ = 3.30E-10; woman HQ = 3.43E-10), Chloroethane (child HQ = 1.41E-05; man HQ = 1.03E-05; woman HQ = 1.07E-05), dichloromethane (child HQ = 9.66E-06; man HQ = 7.07E-06; woman HQ = 7.36E-06), ethylbenzene (child HQ = 5.19E-05; man HQ = 3.80E-05; woman HQ = 3.95E-05), and hydrogen sulfide (child HQ = 7.99E-08; man HQ = 5.85E-08; woman HQ = 6.09E-08).

For the carcinogenic effect there also was the acceptable risk exposure to the acrylonitrile (child Life time cancer risk for carcinogenic risk (LCR) = 4.84E-13; man LCR = 9.76E-14; woman LCR = 9.51E-14), carbon tetrachloride (child LCR = 2.70E-17; man LCR = 5.44E-18; woman LCR = 5.30E-18), chloroform (child LCR = 7.77E-16; man LCR = 1.56E-16; woman LCR = 1.52E-16), and dichloromethane (child LCR = 1.61E-16; man LCR = 3.24E-17; woman LCR = 3.16E-17).

LFG constituents	Group[a]	(Non-Carcinogenic effect), m^3/kg/yr.	Hazard Quotient (HQ) for non-carcinogenic risk	Risk	(Carcinogenic effect), m^3/kg/yr.	Life time cancer risk (LCR) for carcinogenic risk	Risk
Acrylonitrile	Child	7.12E+00	1.42E-08	Acceptable	7.12E+00	4.84E-13	Acceptable
	Adult Man	5.22E+00	1.04E-08	Acceptable	1.44E+00	9.76E-14	Acceptable
	Adult Woman	5.43E+00	1.09E-08	Acceptable	1.40E+00	9.51E-14	Acceptable
Carbon disulfide	Child	6.53E-01	4.57E-07	Acceptable	NA	NA	-
	Adult Man	4.78E-01	3.35E-07	Acceptable	NA	NA	-
	Adult Woman	4.97E-01	3.48E-07	Acceptable	NA	NA	-
Carbon tetrachloride	Child	4.50E-03	4.50E-10	Acceptable	4.50E-03	2.70E-17	Acceptable
	Adult Man	3.30E-03	3.30E-10	Acceptable	9.07E-04	5.44E-18	Acceptable
	Adult Woman	3.43E-03	3.43E-10	Acceptable	8.84E-04	5.30E-18	Acceptable
Carbonyl sulfide	Child	NA	NA	-	NA	NA	-
	Adult Man	NA	NA	-	NA	NA	-
	Adult Woman	NA	NA	-	NA	NA	-
Chlorobenzene	Child	NA	NA	-	NA	NA	-
	Adult Man	NA	NA	-	NA	NA	-
	Adult Woman	NA	NA	-	NA	NA	-
Chloroethane	Child	1.41E+00	1.41E-05	Acceptable	NA	NA	-
	Adult Man	1.03E+00	1.03E-05	Acceptable	NA	NA	-
	Adult Woman	1.07E+00	1.07E-05	Acceptable	NA	NA	-
Chloroform	Child	NA	NA	-	3.38E-02	7.77E-16	Acceptable
	Adult Man	NA	NA	-	6.80E-03	1.56E-16	Acceptable
	Adult Woman	NA	NA	-	6.63E-03	1.52E-16	Acceptable
Dichloromethane	Child	1.61E+01	9.66E-06	Acceptable	1.61E+01	1.61E-16	Acceptable
	Adult Man	1.18E+01	7.07E-06	Acceptable	3.24E+00	3.24E-17	Acceptable
	Adult Woman	1.23E+01	7.36E-06	Acceptable	3.16E+00	3.16E-17	Acceptable
Ethylbenzene	Child	5.19E+00	5.19E-05	Acceptable	NA	NA	-
	Adult Man	3.80E+00	3.80E-05	Acceptable	NA	NA	-
	Adult Woman	3.95E+00	3.95E-05	Acceptable	NA	NA	-
Hydrogen Sulfide	Child	4.00E+01	7.99E-08	Acceptable	NA	NA	-
	Adult Man	2.93E+01	5.85E-08	Acceptable	NA	NA	-
	Adult Woman	3.04E+01	6.09E-08	Acceptable	NA	NA	-

[a] Potential health risk exposure was estimated for difference inhalation rate (15m^3/day-child; 23m^3/day-Adult man; 21m^3/day-Adult woman [39], lifetime expectancy (Female: 77.6 and Male: 72.7 [6], and average body weight (Child: 31.8 kg [39]; Adult man: 66.56kg; and Adult woman 58.44 [40].

NA = the inhalation Reference Concentration (Rfc) / Unit Risk Factor is not available in the Integrated Risk Information System (IRIS) to identify the risk of the compounds.

Table 3: The estimation of the inhalation exposure to NMOCs emission in the landfill

Management cost

Table 4 shows the descriptive analysis of estimated waste management costs for collection and transportation, leachate treatment, land use, and landfill tipping fees of solid waste generation in Klang from 2011 to 2017 (7 years). In average (mean±SD), waste collection and transportation in Klang required 21,156 million MYR (Malaysian Ringgit) ±1,705 million (5,126 million USD

±413,346.81) / year. For leachate treatment, the estimated cost was 1,467 million MYR ±118,291.91 (355,446.76 USD±28,661.30) / year. The cost for land use was 593, 928.57 MYR ±48,279.94 (143,904.74 USD ±11,697.89) / year with the landfill tipping fees of 8,382 million MYR ±675,954.00 (2,031 million USD ±163,778.92) / year.

Year	Management cost, MYR (USD)[a]			
	Collection and Transportation	Leachate treatment	Land use (landfill space)	Landfill tipping fee
2011	18,969,077.36 (4,596,074.66)	1,315,308.75 (318,690.10)	532,500.00 (129,021.02)	7,516,049.52 (1,821,086.19)
2012	21,027,295.26 (5,094,766.45)	1,458,024.75 (353,269.19)	590,000.00 (142,952.87)	8,331,569.82 (2,018,681.05)
2013	21,108,294.10 (5,114,391.90)	1,463,641.20 (354,630.02)	592,500.00 (143,558.60)	8,363,663.70 (2,026,457.17)
2014	20,582,974.00 (4,987,110.52)	1,427,215.65 (345,804.36)	577,500.00 (139,924.21)	8,155,518.00 (1,976,024.92)
2015	20,334,494.10 (4,926,905.58)	1,409,986.20 (341,629.79)	570,000.00 (138,107.01)	8,057,063.70 (1,952,170.14)
2016	21,526,028.44 (5,215,606.01)	1,492,606.85 (361,648.19)	605,000.00 (146,587.27)	8,529,181.08 (2,066,560.87)
2017	24,550,196.78 (5,948,340.83)	1,702,301.30 (412,455.69)	690,000.00 (167,182.17)	9,727,436.46 (2,356,889.76)
Total	148,098,360.04 (35,883,195.95)	10,269,084.70 (2,488,127.34)	4,157,500.00 (1,007,333.15)	58,680,482.28 (14,217,870.09)
Min	18,969,077.36 (4,596,074.66)	1,315,308.75 (318,690.10)	532,500.00 (129,021.02)	7,516,049.52 (1,821,086.19)
Max	24,550,196.78 (5,948,340.83)	1,702,301.30 (412,455.69)	690,000.00 (167,182.17)	9,727,436.46 (2,356,889.76)
Mean	21,156,908.58 (5,126,170.85)	1,467,012.10 (355,446.76)	593,928.57 (143,904.74)	8,382,926.04 (2,031,124.30)

[a]1MYR (Malaysia Ringgit) = 0.242293 USD (US Dollar), currency on 24th April 2019.

Table 4: The estimation of waste management costs in Klang (2011-2017)

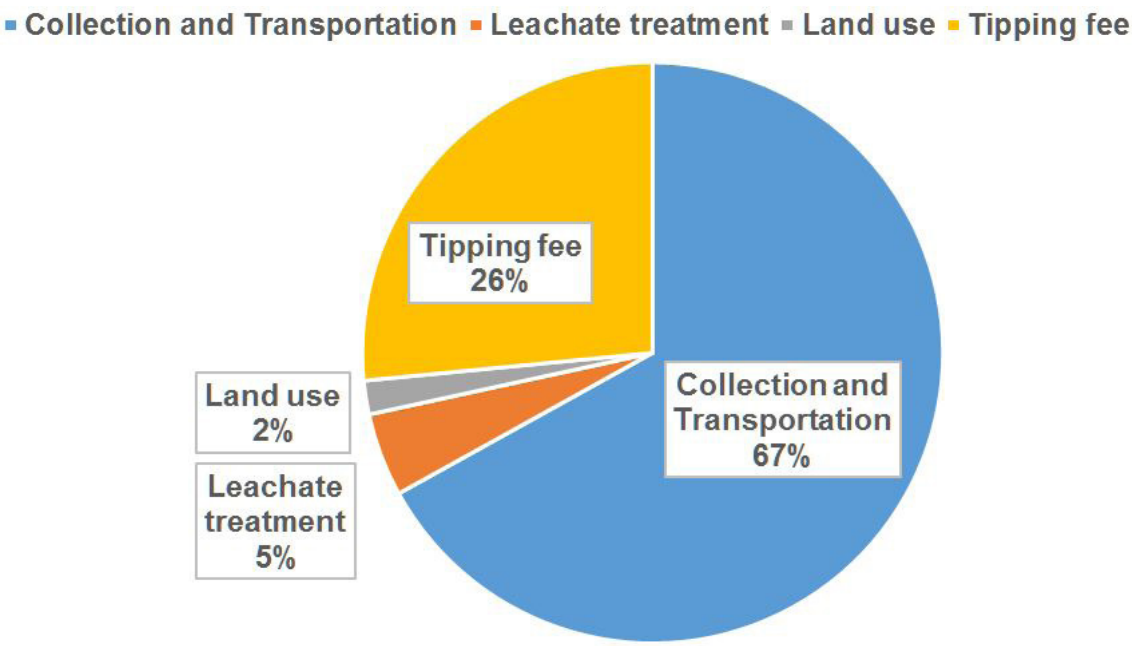


Figure 4: The percentage (%) of waste management costs.

In Figure 4, it shows that collection and transportation were the highest costs (67%) in the waste management element. This followed by landfill tipping fee (26%), leachate treatment (5%), and land use (2%).

Discussion

Waste generation in Klang increased from 12.81% (2011) to 16.58% (2017). The area disposed 199,593.48 t/yr. of solid waste in the

Jeram landfill. The increase in waste generation in Klang is possibly due to the increase in population growth where the average annual population growth rate in Klang is 2.36%/year (861,189 in 2010). They generate 1.35 kg/capita/day of waste and only 9.4% of waste is recycled [5]. In Malaysia, the 3R program (reduce, reuse, and recycling) has started since 1993, however, the 3R practice is still low due to factors such as knowledge, awareness, time and space, household income, facility, and incentives [28,29].

The development of manufactures and services could increase the population in Klang. For example, the township project and LRT3 transit, which is still under development, will boost migration to the area. People's demands also lead to rapid urbanisation and industrialisation. The change of land use from agriculture or forest to land city in the Klang area increased from 11,444 ha in 1997 to 15,890 in 2006 [30]. For example, the use of the land area for the development of supermarkets (e.g. One Kesas Mall, AEON Bukit Tinggi, KSL City Mall, and Tesco) provided job opportunities and changed people's lifestyles. These are potential factors behind waste generation in Klang over time.

On average (2011-2017), disposed solid waste in the landfill emitted 8,655.43 t/yr. of methane (CH_4) that is equivalent to 216,385.85 t/yr. of carbon dioxide (CO_2). The CH_4 emission increased from 7,760.38 t (equivalent to 194,009.44 t of CO_2-eq) in 2011 to 10,043.65 t (equivalent to 251,091.28 t of CO_2) in 2017. The result showed that the emission was proportional to solid waste generation in Klang. According to Anwar, Saeed, Haslenda, Habib and Mat (2012), Selangor is the highest generator of GHG emission (60,370 t/yr. of methane) followed by Johor (52,800 t/yr.) and Kuala Lumpur (45,500 t/yr.) [31]. It has been reported that landfills are one of the sources of GHG emissions that release 50% methane (CH_4), 45% carbon dioxide (CO_2), and 5% other gases (i.e. hydrogen sulfide, nitrogen, non-methane organic compounds [NMOC]) [32,33].

In this study, the estimation of leachate production in the landfill was 41,914.63 cubic meter per year (m^3/yr.). Leachate production increased from 34,047.71 m^3 in 2011 to 44,065.29 m^3 in 2017 that was proportional to the volume of solid waste disposed of in the landfills. This study estimated the volume of leachate produced in the landfill based on the volume of solid waste disposed of in the landfill where one tons of waste generates 0.21m^3 of leachate [3]. In contrast, another case study in Malaysia reports that the volume of leachate in the landfills is around 899 to 9,343 m^3/year when it was estimated based on the rainfall intensity and landfill surface area [34]. The disposal of mixed wastes in landfills produces leachate containing heavy metals [35]. Therefore, five selected heavy metals (i.e. lead [Pb], zinc [Zn], chromium [Cr], copper [Cu], and Cadmium [Cd]) were analyzed in this study. On average, the result of the study reported that the highest volume of heavy metals in landfill leachate was 35% Pb (0.63 kg/yr.) and 35% Zn (0.63 kg/yr.), followed by 14% Cr (0.25 kg/yr.), 12% Cu (0.21 kg/yr.) and 4% Cd (0.08 kg/yr.).

The disposal of Klang's solid waste (199,593.48 t/yr.) required 2.38 ha/yr. of landfill space. The use of landfill space increased from 2.13 ha in 2011 to 2.76 ha in 2017 as the volume of disposed solid waste in the landfill increased. This shows that disposal of huge amounts (tons) of solid waste or depending only on the landfill method will reduce the lifespan of landfills and require the rapid construction of a new landfill that can cause the destruction of natural resources.

The highest NMOC emission was hydrogen sulfide (2.35E-01 m^3/yr.), followed by dichloromethane (9.47E-02 m^3/yr.), acrylonitrile (4.19E-02 m^3/yr.), ethylbenzene (3.05E-02 m^3/yr.), chloroethane (8.27E-03 m^3/yr.), carbon disulfide (3.84E-03 m^3/yr.), carbonyl sulfide (3.24E-03 m^3/yr.), chlorobenzene (1.66E-03 m^3/yr.), chloroform (1.99E-04 m^3/yr.), and carbon tetrachloride (2.64E-05 m^3/yr.). The health risk (carcinogenic and non-carcinogenic) exposure to the NMOC annually was analyzed. The study reported that there was an acceptable risk for non-carcinogenic effects (acrylonitrile, carbon disulfide, carbon tetrachloride, chloroethane, dichloromethane, ethylbenzene, and hydrogen sulfide) and carcinogenic effects (acrylonitrile, carbon tetrachloride, chloroform, dichloromethane) for a child, an adult man, and an adult woman. This may be because landfill gas contains only 0.5-1% of NMOC [33]. However, it is important to assess their levels in the landfill as they are toxic substances that can cause adverse effects to residents in the vicinity [36].

On average, the estimated cost for waste management in Klang was 1,705 million MYR/year. (5,126 million USD/year) for waste collection and transportation, 1,467 million MYR/year (355,446.76 USD/year) for leachate treatment, 593,928.57 MYR/year (143,904.74 USD/year) for land use (i.e. landfill space required for waste disposal), and 8,382 million MYR/year (2,031 million USD/year) for landfill tipping fees. Based on the result of the study, collection and transportation were the highest costs (67%) in the waste management elements assessed in this study. This was followed by landfill tipping fee (26%), leachate treatment (5%), and land use (2%). According to Hoornweg and Perinaz (2012) [1], in middle-income countries, (e.g. Malaysia, Thailand, India, Indonesia, Philippines, Vietnam) around 50% to 80% of MSW management budget is allocated for waste collections. Community participation in the waste reduction program is the best way to reduce waste management costs including the cost for collection, transportation, disposal, and recycling [1,37].

Conclusion and Recommendations

Waste generation in Klang increased from 12.81% in 2011 to 16.58% in 2017 that was proportionate to the methane and carbon dioxide equivalent emission. The disposal of huge amounts of waste in the landfill produces a high volume of leachate containing heavy metals (i.e. Pb, Zn, Cr, Cu and Cd). The disposal of high volumes of waste also required more land space area which depends only on the landfilling method will reduce its lifespan.

The highest non-methane organic compounds emission was hydrogen sulphide, followed by dichloromethane and acrylonitrile.

There was an acceptable risk for carcinogenic and non-carcinogenic exposure to the NMOC for all groups (child, adult man, and adult woman). Collection and transportation are the highest costs (67%) in the waste management element. This is followed by landfill tipping fee (26%), leachate treatment (5%), and land use (2%).

In conclusion, proper waste management through systematic planning and strategy is important to reduce its impact on the environment and ensure betterment of human life. The findings of the study can be used by the government as an initial step of the assessment to support their decision making. In the future, a comprehensive study which considers the environmental, health, and economic impact or contributions should be conducted to identify a sustainable method of solid waste management for the country. A study on other approaches of waste management such as the pay-polluter principle, source segregation, recycling, biological treatment (i.e. aerobic composting and anaerobic digestion) and incineration (waste to energy) should be conducted in a future study to analyze their potential contributions on the environment and minimize health risk and economic contributions (i.e. provide profits to the country).

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