UNIVERSITI PUTRA MALAYSIA

POTENTIAL CONTRIBUTION OF POLLUTER PAYS PRINCIPLE (PPP) ON REDUCTION OF ENVIRONMENTAL POLLUTION AND HEALTH RISK FOR MUNICIPAL SOLID WASTE (MSW) IN KLANG.

MOHD FILZA IKMAL BIN IROZI

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BY

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Thesis submitted in fulfilment of the requirement for the degree of Bachelor Science (Environmental and Occupational Health) from the Faculty of Medicine and Health Sciences, Universiti Putra Malaysia.

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ABSTRACT

POTENTIAL CONTRIBUTION OF POLLUTER PAYS PRINCIPLE (PPP) ON REDUCTION OF ENVIRONMENTAL POLLUTION AND HEALTH RISK FOR MUNICIPAL SOLID WASTE (MSW) IN KLANG.

MOHD FILZA IKMAL BIN IROZI

Introduction: Malaysia generates 38,000 tonne of solid waste per day and 89% of waste collected ending up in landfills. The problems of disposal of solid waste in the landfill had caused environmental pollution (air and water pollution) and affect human health. Polluter pays principle (PPP) is a waste management scheme and Pay As You Throw is one of the approach to overcome solid waste management problems. **Objective:** To estimate the potential contribution of polluter pays principle (PPP) on reduction of environmental pollution and health risk for municipal solid waste (MSW) in Klang. **Methodology:** The volume of MSW disposed (tonnes) in Jeram landfill were obtained from Majlis Perbandaran Klang from 2011 to 2017 and analysed by using mathematical equations to estimate the level of environmental pollution and health risk. **Results:** The average volume of waste disposed in Jeram landfill was 199,593.48 ±16,094.14 t/year. The volume has increased by 29.4% between from 14,912.80 t/month ± 821.17 in 2011 to 19,300.47 t/month ± 829.44 in 2017. Prediction on waste composition made based on the average percentage provided by the National Solid Waste Department. Food waste dominating the percentage in household waste composition (57,472.94 tonnes/year ±4634.30 tonnes/year) followed by institutional, commercial, and industrial waste composition (21935.32 ±1768.75). The emission of CH_4 and CO^2-eq in scenario 1 were (6058.96 tonnes/year, 151,473.88 tonnes/year), scenario 2 (5,193.39 tonnes/year, 145,414.93 tonnes/year), and scenario 3 (4,327.83 tonnes/year, 121,179.11 tonnes/year) respectively. The volume of leachate produced in scenario 1, scenario 2 and scenario 3 were 29,340.24 m^3, 25,148.78 m^3, 20,957.32m^3. The total heavy metals production in leachate in scenario 1, scenario 2, and scenario 3 were 1.26 kg/year, 1.08 kg/year, and 0.901 kg/year. The total production of non-methane organic compound in scenario 1, scenario 2 and scenario 3 were 2.93E-01 m^3, 2.52 E-01 m^3, and 2.09E-01 m^3. **Conclusion:** The implementation of PPP has potential on reduction of environmental pollution (air and water pollution) and health risk by reducing the total waste disposed in the landfill.

Keywords: Landfill, municipal solid waste, polluter pays principle (PPP)

ABSTRAK

POTENSI SUMBANGAN PRINSIP BAYARAN PENCEMAR DALAM PENGURANGAN PENCEMARAN ALAM SEKITAR DAN RISIKO KESIHATAN BAGI SISA PEPEJAL PERBANDARAN DI KLANG

MOHD FILZA IKMAL BIN IROZI

Pengenalan: Malaysia menghasilkan 38,000 tan sisa pepejal setiap hari dan 89% sisa sampah yang terkumpul di tapak pelupusan sampah. Masalah pembuangan sisa pepejal di tapak pelupusan telah menyebabkan pencemaran alam sekitar (pencemaran udara dan air) dan menjejaskan kesihatan manusia. Prinsip Bayaran Pencemar(PPP) adalah skim pengurusan sisa dan Pay As You Throw adalah salah satu pendekatan untuk mengatasi masalah pengurusan sisa pepejal. **Objektif:** Untuk menganggarkan sumbangan berpotensi untuk Prinsip Bayaran Pencepar(PPP) mengenai pengurangan pencemaran alam sekitar dan risiko kesihatan untuk sisa pepejal perbandaran (MSW) di Klang. **Metodologi:** Jumlah MSW yang dilupuskan (tan) di tapak pelupusan Jeram diperoleh dari Majlis Perbandaran Klang dari 2011 hingga 2017 dan dianalisis dengan menggunakan persamaan matematik untuk menganggarkan tahap pencemaran alam sekitar dan risiko kesihatan. **Keputusan:** Jumlah purata sisa yang dibuang di Tapak Jeram ialah 199,593.48 ± 16,094.14 t / tahun. Jumlah ini meningkat sebanyak 29.4% antara 14,912.80 t / bulan ± 821.17 pada tahun 2011 kepada 19,300.47 t / month ± 829.44 pada tahun 2017. Ramalan mengenai komposisi buangan dibuat berdasarkan peratusan purata yang disediakan oleh Jabatan Sisa Pepejal Negara. Sisa makanan menguasai peratusan komposisi sisa isi rumah (57,472.94 tan / tahun ± 4634.30 tan metrik / tahun) diikuti oleh komposisi sampah institusi, komersial dan industri (21935.32 ± 1768.75). Pelepasan CH_4 dan CO_2-eq dalam senario 1 adalah (6058.96 tan metrik / tahun, 151,473.88 tan metrik / tahun), senario 2 (5,193.39 tan metrik / tahun, 145,414.93 tan / tahun) dan senario 3 (4,327.83 tan metrik / masing-masing). Jumlah larutan resin yang dihasilkan dalam senario 1, senario 2 dan senario 3 adalah 29,340.24 m3, 25,148.78 m3, 20,957.32m3. Jumlah pengeluaran logam berat dalam larut dalam senario 1, senario 2, dan senario 3 adalah 1.26 kg / tahun, 1.08 kg / tahun, dan 0.901 kg / tahun. Pengeluaran total sebatian organik bukan metana dalam senario 1, senario 2 dan senario 3 adalah 2.93E-01 m3, 2.52 E-01 m3, dan 2.09E-01 m3. Kesimpulan: Pelaksanaan PPP berpotensi untuk mengurangkan pencemaran alam sekitar (pencemaran udara dan air) dan risiko kesihatan dengan mengurangkan jumlah sisa yang dilupuskan di tapak pelupusan.

Kata kunci: Tapak pelupusan sampah, sisa pepejal perbandaran (MSW), Prinsip Bayaran Pencemar (PPP)

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LIST OF ABBREVATIONS

PPP	Polluter Pays Principle
US EPA	United States Environmental Protection Agency
MSW	Municipal solid waste
NMOC	Non-methane organic compound
PAYT	Pay as you throw
SWM	Solid waste management
JPSPN	Jabatan Pengurusan Sisa Pepejal Negara
SWDSs	Solid waste disposal sites
GHG	Green-house gases
HQ	Hazard Quotient
LCR	Lifetime cancer risk
IPCC	Intergovernmental Panel on Climate Change
MHLG	Ministry of Housing and Local Government
GWP	Global warming potential
ROS	Reactive oxygen species
IARC	International Agency for Research on Cancer

MPK	Majlis Perbandaran Klang
DOC	Degradable organic compound
MSWF	Municipal solid waste fraction
DOCF	Degradable organic carbon fraction

CHAPTER 1

INTRODUCTION

1.1 Background

Solid waste management is a global challenge in economically developing country such as Malaysia due to several factors such as rapid growing of populations, life style changes, rising community standards (Hassan et al, 2016). These factors will lead increasing in solid waste generation. Tarmiji et al., (2011) had stated in their study that Malaysian population statistics in urban area has increasing more than 50% in the last few decades. Furthermore, the solid waste characteristics in Malaysia have changed due to rapid urbanization and industrialization (Latifah et al., 2009). Latifah and Yiing (2017) stated that in their study, with significant advancement of living standards, it is unpreventable that solid waste generation increases over the years without any transformation in the attitudes and habits of Malaysian in managing their waste. The solid waste generation increases at uncontrollable rate because of plastic and paper utilization especially in packaging where those materials become dispensable to the consumers (Abdul Jalil, 2010).

Based on US EPA definition, municipal solid waste is waste consisting of everyday items from homes, institutions such as school and hospital, and commercial sources such as restaurants. The example of municipal solid waste are product packaging, grass clippings, furniture, clothing, bottles and cans, food scraps, newspapers, appliances, consumer electronics and batteries. The overall solid waste composition in Malaysia is dominated by municipal solid waste (64%) with the remaining consists of industrial waste, commercial waste, and construction waste (SWMC, 2009).

The rapid development in Malaysia had accelerated the daily waste production where 30,000 tonnes of the total population is approximately 29.2 million in the year of 2012. Respectively, the total solid waste generated per year was 10.9 million tonnes. However, the solid waste generation highly increased to 38,000 tonnes as 12.8 million tonnes of solid waste generated per year in the year of 2015. The solid waste generation predicted to increase 15.6 million tonnes in year 2020 (Agamuthu and Dennis, 2011). Deputy of Urban Wellbeing, Housing and Local Government Minister Datuk Halimah Mohd Sadique had stated that the ministry viewed this issue as a major problem in Malaysia due to the latest figure has exceeded the government's projected waste production of 30,000 tonnes daily by year 2020. As studied by Hoornweg & Perinaz (2012), the current global MSW generation is 1.3 billion tonnes per year and expected will increase up to 2.2 billion tonnes per year in 2025 with generation per capita will increase from 1.2 to 1.4 kg/capita/day. Malaysia is the highest rate of generation per capita with average 1.03 kg/capita/day compared to other Asian countries such as Thailand (1.0 kg/capita/day), South Korea (0.99 kg/capita/day), Japan (0.98 kg/capita/day), Indonesia (0.70 kg/capita/day), China (0.63 kg/capita/day) and India (0.5 kg/capita/day) (Hoornweg & Perinaz, 2012).

Malaysia is highly dependent on landfills as the main disposal method with 89% of waste collected ending up in the landfills (JPSPN, 2013). The highly dependency will led to the potential threat to the environment, society and economic losses as the dependence on the landfill which particularly causing a serious environmental problems such as soil contamination, leachate, gas emission and air pollution (Shekdar, 2009). Furthermore, it will cause flood, proliferation of insects, vector disease outbreak and contaminate surface and ground water which causing huge responsibility to the local authority (Alam and Ahmade, 2013). Moreover, the problems of disposal of solid waste in landfill can give negative impact to the human health and causing green-house gases emission (Chadar & Keerti, 2017).

The polluter-pays principle stands as an international guideline for environmental policy stipulating that the person or firm who damages the environment must bear the cost of such damage (Luppi et al., 2011). The implementation of variable pricing mechanisms from municipalities, often referred to as pay-as-you-throw (PAYT), is a powerful instrument available to local authorities to support and optimize waste management policy and improve the situation of urban waste generation by increasing waste separation and recycling (Habil,2008). (PAYT) is a strategy in which customers are provided an economic signal to reduce the waste they throw away, because garbage bills increase with the volume or weight of waste they dispose (Skumatz, 2008).

1.2 Research Justification

The importance of this study is to promote and improve the management of municipal solid waste in Malaysia. This study will suggest to reduce the negative impact to the environment and human health by introducing economic instrument through national or regional waste policies such as waste disposal taxes, waste pricing, deposit refund schemes, and recycling subsidies. This study also is important for the government to review the existence of MSW management and come out with the best and most appropriate methods to ensure sustainability of the resources by various means such as enforcement of waste regulation, recycling, waste control at source, the design of an intelligence system to control the composition of municipal waste and continuous awareness campaign on waste related issues to the population. Furthermore, this study is important to control the generation of municipal solid waste from the consumer and reduce the volume of waste being sent to the landfills.

1.3 Problem Statement

The effective solid waste management continues to be a major challenge in the developing countries including Malaysia, whereby experienced a rapid increasing of urban population and its solid waste generation. Statistics shows the Malaysian population in urban area has increasing more than 50% in the last few decades (Tarmiji et al., 2011). The number of cities in peninsular Malaysia has increased 400% in 2000, as compared to the number of city in 1957 (Tarmiji et al., 2012). Rapid urbanization and industrialization transition in Malaysia have changed the solid waste characteristics (Latifah et al., 2009). Respectively, solid waste generation has increased to 38,000 tonnes as 12,8 million tonnes of solid waste generated per year and predicted to increase 15.6 million in year 2020 (SWCorp, 2014). Solid waste management is one of the crucial factors that influencing the quality of life in urban area (Baud, 2001).

The problem of solid waste pollution continues to rise reflecting the inefficiency and ineffectiveness of solid waste management system which including solid waste storage, collection, transportation and disposal (Nadzri and Larsen, 2012). Our country is highly dependent on landfilling as the main disposal method in managing the continuous increase of solid waste generation annually (Latifah & Yiing, 2016) with 89% of waste collected ending up in the landfills (SWM, 2012). Landfill is the most common and preferable disposal method that considers the social and economic aspects in developing country, however it is the least preferable in waste management hierarchy (Afzanizam, 2016). The disposal of waste in the landfill is a critical issue in waste management hierarchy because there are no technologies available to avoid the production of unwanted residue from the waste sector and no endowment for zero waste (Fauziah & Agamuthu, 2012). According to JPSPN (2017), there are 158 operating landfills in Malaysia that consist of 17 sanitary landfills and 141 non-sanitary landfills. For instance, there are 8 operating landfills in Selangor that consist of 4 sanitary landfills and 4 non sanitary landfills (KPKT, 2016).

Solid waste disposal sites (SWDSs) that include both managed landfills and unmanaged dump sites were recognized as major green-house gas (GHG) emission sources in developing countries (Tomonori et al.,2011). The deposited waste in the landfill that contain organic material such as food, paper and wood will undergo decomposition process by microbes under anaerobic conditions and will produce methane, carbon dioxide and other gases compound (Afzanizam, 2016). Landfills generates GHG such as Methane (50%), Carbon Dioxide (45%) and other gases and non-methane organic compounds (5%) from the biodegradation process that contribute to climate change and global warming. Methane is a potent GHG, with 21 times the global warming potential of carbon dioxide (Tomonori et al., 2011). The atmospheric methane concentration reported increasing at the rate of 1% per year and the most common sources of methane emission comes from landfills, coal mining, and the production and distribution of natural gas (Thorneloe & Peer, 2015). The aggregate methane discharge and those from waste management represent 14.3% and 2.8% individually of the world wide greenhouse gases outflows in 2004. Hoornweg and Perinaz, (2012) stated in their study that 5% of GHG emission from the landfills contributes to the global warming. Furthermore, the climate change and global warming will affect the human health, assets, economies and ecosystem (IPCC, 2014). For instance, the climate change related risk to population and environment includes heat waves, heavy precipitation, drought, vector borne disease, food and water borne disease and malnutrition.

The disposal of waste in the landfill will produce leachate as a result of percolation of water which is mainly rain water through waste dumps (Prabpai et al., 2009). Leachate is a heterogenous mixture that contains simple and complex compounds that are depends on the characteristics of the waste (Fauziah and Agamuthu, 2012). Heavy metal is one of the most hazardous components in leachate (Sumaiya et al., 2014). The disposal of the residual waste in the landfill will produce leachate containing heavy metals such as mercury, cadmium, copper, zinc, leand and iron (Vasanthi, Kaliappan, & Srinivasaraghavan, 2008). Agamuthu & Fauziah (2010) analysed that the concentration of heavy metals in leachate is higher during the acidogenic phase of waste due to the generation of acids in aerobic conditions. Furthermore, the disposal of electronic waste, painting waste and batteries in the landfill will increase the volume of heavy metal in the leachate (Agamuthu & Fauziah, 2010). Heavy metal contaminations occur due to the subsequent migration of leachate from and within the landfill's waste cell (Agamuthu & Fauziah, 2010).

The disposal of waste in the landfill will cause contamination especially to surface water, soil, and ground water that can threaten the health of exposed populations and ecosystems (Zhang et al., 2010). This scenario provides breeding area for biological vector such as flies, rodents, and insects and can cause disease like diarrhoea, dengue fever, cholera, leptospirosis and dysentery (Pradyumna, 2013). Furthermore, the air pollutants emitted from the landfill contributes to the emission of greenhouse gases and can cause serious problems to the human health (Chalvatzaki & Lazaridis, 2010). The climate change will give negative impact to human health mainly exacerbating the health problems that already exist especially in low income developing country (IPCC, 2014). For instance, the exposure to NMOCs can cause potential health risk such as cardiorespiratory failure and cancer (HPA, 2011). According to Agamuthu &Fauziah (2010), the release of heavy metal from the landfill into the environment is a serious environmental concern and can give threat to public health and safety.

Polluter Pay Principle (PPP) is a waste management scheme and pay as you throw (PAYT) is one of the approaches applied in this principle (Morlok et al., 2017). The aim of economic approach is to promote material recovery among waste producers (Morlok et., 2017). Some municipalities have adopted PAYT programs to educate the residents on the cost of waste disposal and promote the community efforts towards waste reduction (Di Leo & Salvia, 2017). PAYT has led to the diversion of 6.5 million tons of municipal solid waste (MSW) per year in US (Skumatz & Freeman, 2006). As indicated by Lee & Paik (2010) in their study that recycling has increased up to 59.8% while landfill has decreased down to 20.3% after implementation PAYT in Korea. Therefore, this study was designed to assess the potential contribution of polluter pays principle (PPP) on reduction of environmental pollution and health risk for municipal solid waste (MSW) in Klang. According to Sabariah et al., (2018) a proper solid waste management can fortify a sustainable development of Malaysia in many aspects (health, socio-economy and environment) respectively towards Sustainable Development Goals (SDG) to achieve a better and more sustainable future for all.

1.4 Conceptual Framework

This study was conducted to assess the potential contribution of polluter pays principle (PPP) on reduction of environmental pollution and health risk for municipal solid waste (MSW) in Klang. The assessment will be analysed by using mathematical modelling and statistical analysis to identify the contribution of PPP to the environment and health of the populations. The independent variables of this study are the disposal method of municipal solid waste (landfilling), while the dependent variables of this study are the effects of landfilling to the environment and health of the population.

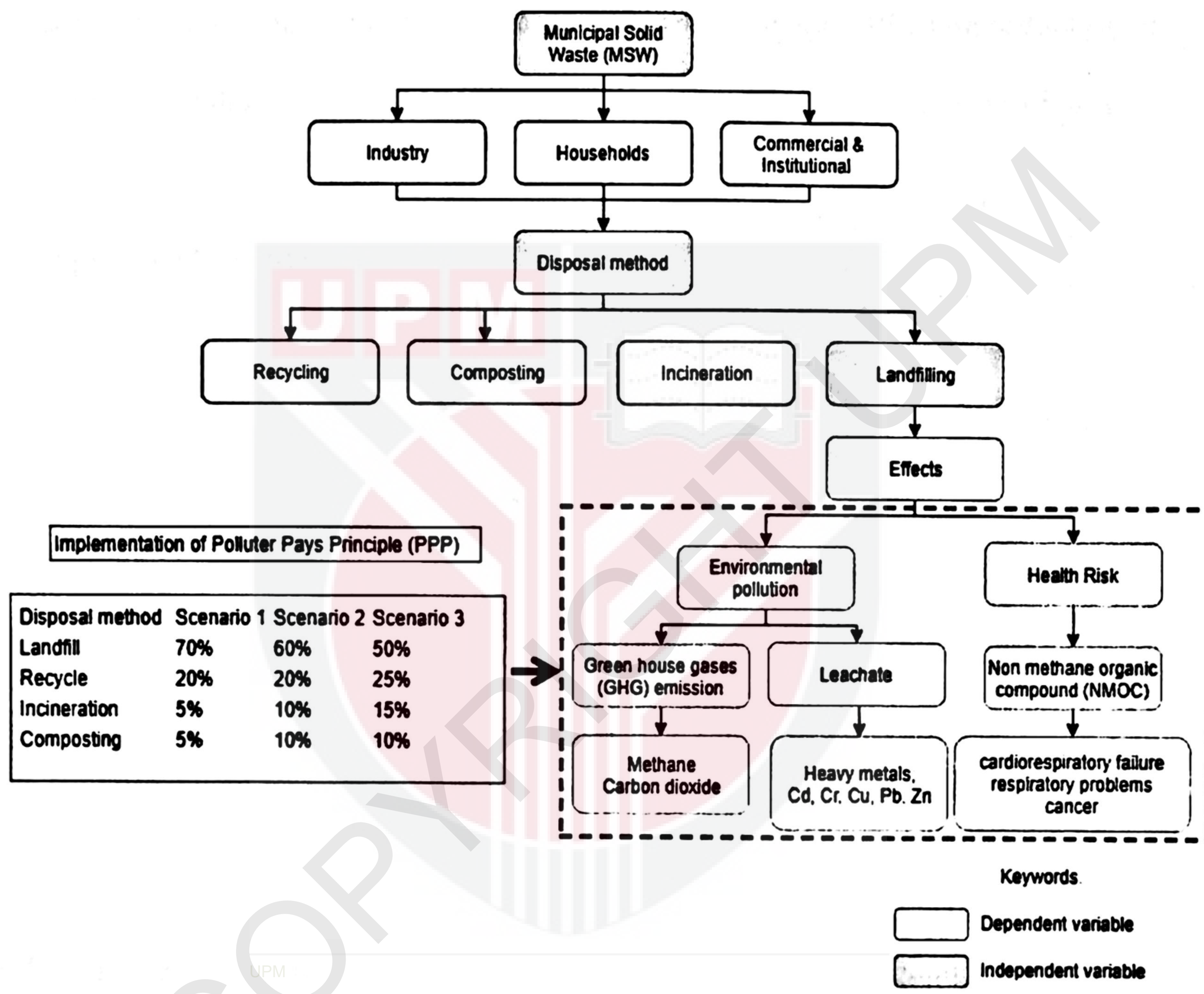


Figure 1.1: Conceptual Framework

1.5 Objectives

1.5.1 General Objectives

To analyse the potential contribution of polluter pays principle (PPP) on reduction of environmental pollution and health risk for municipal solid waste (MSW) in Klang.

1.5.2 Specific Objectives

1. To determine the volume and characteristics of solid waste disposed in landfills from 2011 to 2017 in Klang.
2. To determine the level of GHG emission (CH_4, $C0_2$), environmental pollution and health risk of the current waste landfilling practice in the study area.
3. To determine level of GHG emission (CH_4, CO_2), environmental pollution and health risk of PPP implementation scenario's in the study area.

1.6 Definition of Terms

1.6.1 Conceptual Definition

i. Municipal Solid Waste (MSW)

Municipal solid waste was described as trash or any garbage that consist of everyday items that people use and throw away after the usage such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint and batteries (USEPA, 2016). The sources of

MSW are come from various sources such as homes, institutions (school and hospital), and commercial sources (restaurants).

ii. Polluter Pays Principle (PPP)

Polluter pays principle (PPP) is the policy instrument to promote the internalization cost taking into account that the polluter should bear the cost of the pollution regard to the public interest (Zahar, 2018). According to Luppi et al., (2012), Polluter Pays Principle is a principle that stipulates the person who damages the environment must bear the cost of such damage.

iii. Recycle

Recycling is any process of recovery operation where the materials are reprocessed into products, materials or any other substances whether for original or other purposes (EU, 2008). It does not include the energy recovery and more to reprocessing of organic material. Furthermore, according to Goorhuis & Bartl (2011), recycling contain a set of processes that can be classified into different aspects such as product recycling, material recycling and feedstock recycling. Apart from that, the allocation of procedure for recycling are divided into two cases such as a closed-loop and an open-loop procedure (ISO, 2006a).

iv. Composting

According to Li et al., (2013) composting is a biochemical process converting of organic waste that contain many components into a relatively stable humus-like substances that can be used as a soil amendment or organic fertilizer. Furthermore, composting is the process of biological decomposition or organic material through the generation of heat and stabilized the products that are beneficial to the plant growth (The US Composting Council, 2001).

v. Incineration

According to Patil et al., (2015) incineration is the treatment technology that involving the destruction of solid waste by burning with high temperatures. Incineration is the process that directly controlled burning of waste in the presence of oxygen at temperature of above 800°c. The process also comprise of liberating heat energy, gases and inert ash. The incineration of municipal solid waste (MSW) is beneficial because it can reduce the volume of waste to be landfilled.

1.6.2 Operational Definition

i. Municipal Solid Waste (MSW)

Municipal solid waste is waste from household, institutions, and commercial sector that comprise of many components such as Food and organic waste, plastics, paper, diapers, garden waste, and other waste (glass, textile, metal, e-waste). The weight of the MSW that have been disposed in Jeram sanitary landfill was collected from Majlis Perbandaran Klang from 2011 until 2017.

ii. Polluter Pay Principle (PPP)

Three scenarios of disposal method for MSW have been created based on literature review. The disposal methods for MSW consist of landfill, recycle, incineration and composting with different percentage implementation of Polluter pays Principle. The implementation of PPP will affect the volume of waste for each disposal methods. The level of greenhouse gases (CH_4, CO_2), environmental pollution and health risk will be calculated by using mathematical formula based on weight of the waste for each disposal method.

iii. Recycle

The recycling scenario for MSW has been created based on literature review to assess the potential contribution of polluter pays principle (PPP) on reduction of environmental pollution (greenhouse gases, leachate, heavy metals in leachate) and health risk for municipal solid waste in Klang.

iv. Composting

The composting scenario for MSW has been created based on literature review to assess the potential contribution of polluter pays principle (PPP) on reduction of environmental pollution (greenhouse gases, leachate, heavy metals in leachate) and health risk for municipal solid waste in Klang.

v. Incineration

The incineration scenario for MSW has been created based on literature review to assess the potential contribution of polluter pays principle (PPP) on reduction of environmental pollution (greenhouse gases, leachate, heavy metals in leachate) and health risk for municipal solid waste in Klang.

CHAPTER 2

LITERATURE REVIEW

2.1 Solid waste

According to Solid Waste Management Act 2007 (Act 672), solid waste is defined as any unwanted substances, material or broken, contaminated or worn out that required by authority to be disposed. US EPA (2018) defined solid waste as any garbage or refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, resulting from industrial, commercial, mining, and agricultural operations, and from community activities. Based on US EPA (2016), municipal solid waste is defined as waste consisting of everyday items from homes, institutions such as school and hospital, and commercial sources such as restaurants. The example of municipal solid waste are product packaging, grass clippings, furniture, clothing, bottles and cans, food scraps, newspapers, appliances, consumer electronics and batteries. However, municipal solid waste does not include municipal wastewater treatment sludges, industrial process wastes automobile bodies, combustion ash or construction and demolition debris.

Municipal solid waste also known as the waste that has been generates in the urban area such as from household, institution, industry and commercial centre (Ludwig et al., 2003). The municipal solid waste is heterogeneous that comprise of many materials such as glass, metal, paper and plastics (table 2.1). Municipal solid waste has many categories and is segregated based on their physical compositions such as organic and inorganic waste (table 2.2). The examples of organic waste were food waste, garden waste, paper waste, textiles and rubber waste. Other than that, the inorganic waste consists of metal waste, plastic waste and glass waste.

Zukki, Manaf & Samah (2009) stated that, solid waste in Malaysia is categorized into three major group; municipal solid waste (MSW), schedule or hazardous waste and clinical waste. Each group of solid waste has been managed by different government department or agencies. For instance, the management of municipal solid waste is under the responsibility of Ministry of Housing, and Local Government (MHLG), while for schedule or hazardous waste under responsibility of Department of Environment (DOE) and clinical waste under responsibility of Ministry of Health (MOH).

Albakri (2016) stated that Malaysia generated about 38k tonnes of solid waste per day which is dominated from household. In Selangor, 3000t/day of waste generated in 1997 and the amount of waste has been increase up to 5700t/day in the year 2017. The government has delegated the responsibilities to manage the solid waste management to private sector in order to provide an integrated, effective, efficient and technologically advanced solid waste management system and overcome the issues related to solid waste. The management of solid waste are through recycling, composting, incineration, inert landfill, sanitary landfill and other disposal sites (Ghafar, 2017).

Table 2.1: The sources of municipal solid waste and its types (Franklin Association, 1999)

Source of municipal solid waste	Type of solid waste
Residential	Food waste, food container and packer, bottles, papers, newspaper, clothes, garden waste, furniture waste, e-waste
Commercial centre (office lot, small shop, restaurant)	Papers, boxes, food waste, food container and packer, can, bottles
Institutional (school, university, college, hospital)	Food waste, office waste, garden waste, furniture waste, office waste
Industry (factory)	Cafeteria waste, office waste, processing waste
City centre (drainage and road)	Public waste, construction waste, garden waste

Table 2.2: Physical composition of municipal solid waste (Pichtel, 2005)

Physical composition	Basic classification	Examples
Organic	Food waste	Vegetables, meats
	Garden waste	Dried leaves, twigs, cut grasses
	Textile and rubber	Leather products, clothes
	Paper and box	Newspaper, vary types of paper and box products
Inorganic	Plastics	1 = Polyethylene terephthalate, 2 = High-density polyethylene, 3 = Polyvinyl chloride, 4 = Low-density polyethylene, 5 = Polypropylene , 6 = Polystyrene, 7 = Multilayer Plastic *based on coding plastic system by Plastics Industry Association
	Glass	Glasses products that were used at home, laboratory and etc.
	Metal	Zinc, chromium, ferrous products, type of metal products.

2.2 Solid waste generation in Malaysia

The amount of solid waste are increasing annually due to transformation in economic globalization, emerging technologies that drive urbanization and population increase (Latifah et al., 2018). 1.3 billion ton of solid waste was collected worldwide every year and this amount were expected to reach 2.2 billion tonnes per year by year 2025 (Hoornweg and Bhada-Tata, 2012). In 2012, Malaysia generates 30,000 tonnes of solid waste daily with the total population approximately 29.2 million. Respectively, the total solid waste generated per year waste 10.9 million tonnes. However, the rapid development in Malaysia with the broad transformation is changing the ways how Malaysian life, think and act and cause the solid waste generation has increased to 38,000 tonnes as 12.8 million tonnes of solid waste generated per year in year 2015. The amount of solid waste generation predicted to increase 15.6 million tonnes in year 2020 (Agamuthu and Dennis, 2011; SWCorp, 2014).

According to the National Solid Waste Department of Malaysia, the generation of Municipal solid Waste (MSW) in Malaysia is approximately 1.2 kg per capita daily in 2014 and estimated annual increase of 3.59%. According to the World Bank (2012), the generation rate of MSW for urban cities in Malaysia is 1.52kg per capita in 2012 due to rapid growth of population and urbanization.

2.3 Waste composition

The waste composition of municipal solid waste in Malaysia can be categorized into 6 groups which is; food and organic waste, plastics, paper, diapers, garden and others (glass, textile, metal, e-waste) (SWML, 2015). The waste composition is related to human or community activities such as commercial, institutional, industrial, and markets (Armi Abu Samah et al., 2013).

As shown in figure 2.1, the food and organic waste contribute the biggest component constituting about 44.5% in the national waste composition. Plastics waste and paper waste were 13.20% and 8.50% respectively. Diapers waste has contributed 12.10% of the total waste generated. The diapers waste contributed to the highest waste composition due to the cheaper price and easily accessible of diapers product in the market (JPSPN, 2013).

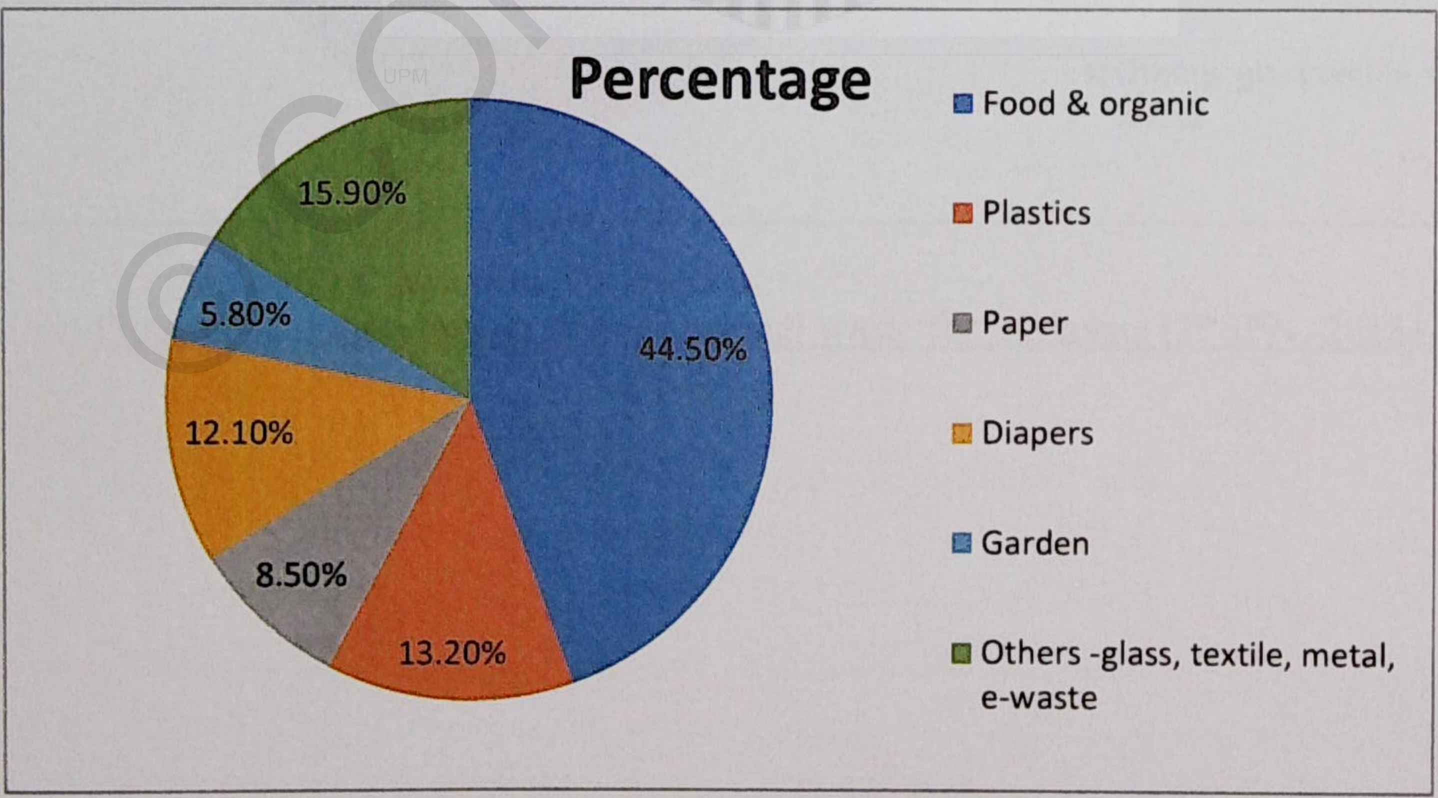


Figure 2.1: Malaysian Household Waste Composition (JPSPN, 2013)

As shown in figure 2.2, the main institutional sector that contribute to the waste composition in Malaysia are from the following categories; schools, college, universities, government offices, polytechnics, hospitals, clinics, and public transportation facilities. Based on the average composition of the waste collected from the various institution in Malaysia, food waste was recorded the highest average with 32.3% followed by plastics at 21.8% and papers at 18.1% (Fig 2.2) (JPSPN, 2013).

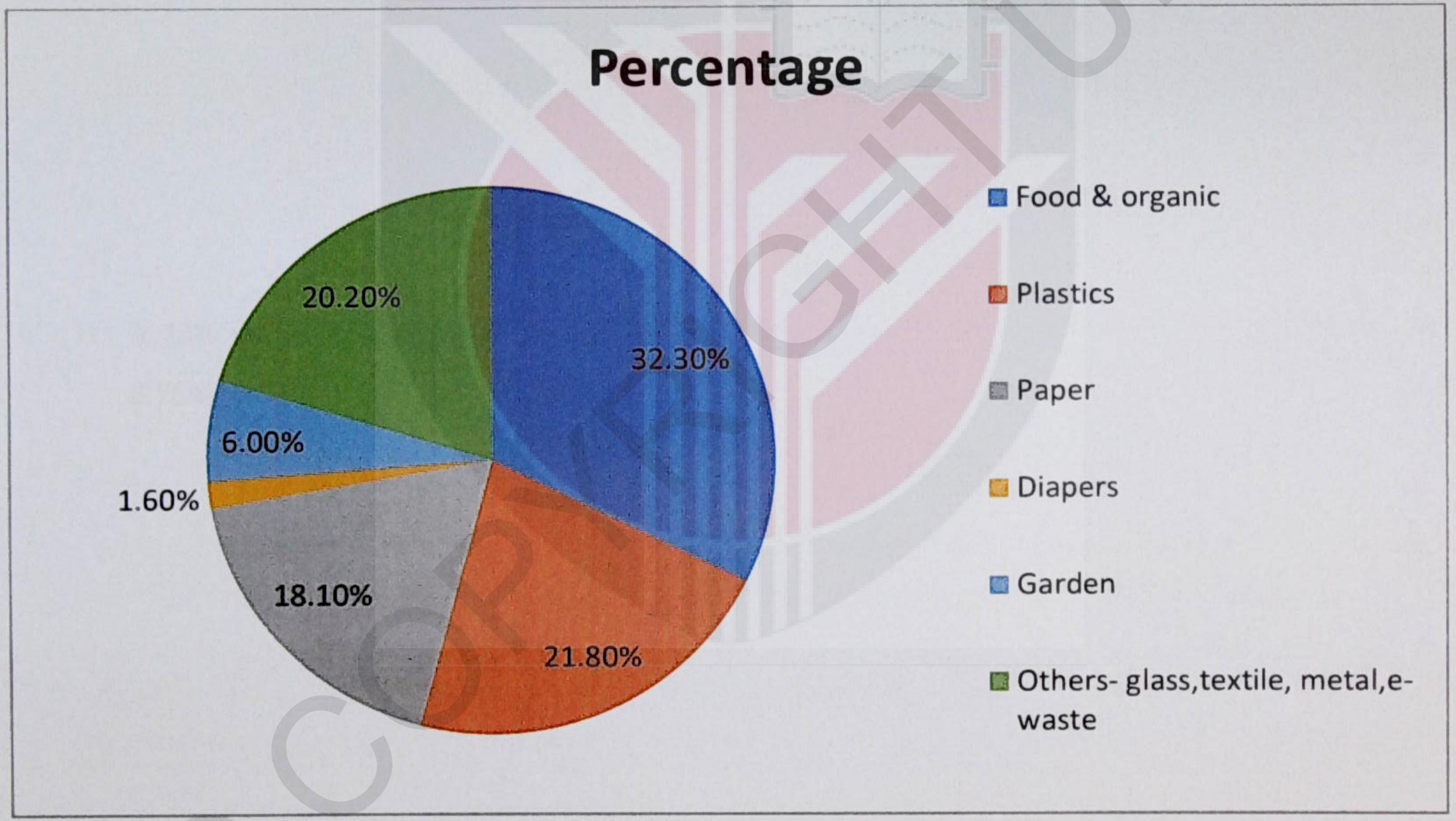


Figure 2.2.: Composition of institutional waste for Malaysia (JPSPN, 2013)

As shown in figure 2.3, the commercial sector in Malaysia comprise of several categories such as markets, supermarkets, shopping complexes, hotels, restaurants, food courts and business lots. Food waste contribute the highest component with an average 40.4% for the average composition of the waste collected from the various commercial facilities in Malaysia. The average of the waste composition followed by plastic and paper at 23.2% and 16.3% respectively (JPSPN, 2013).

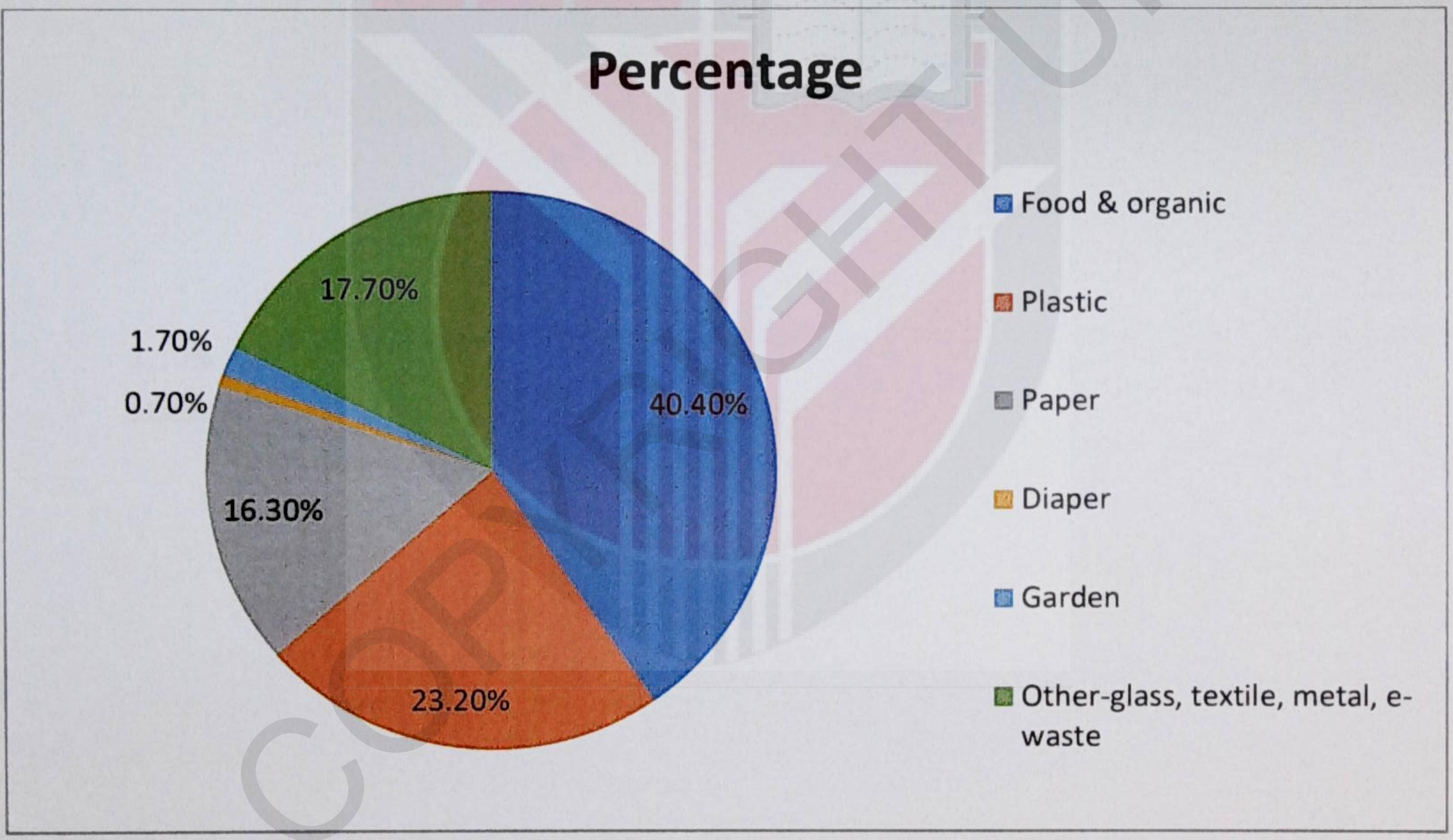


Figure 2.3: Composition of Commercial Sector Waste for Malaysia (JPSPN, 2013)

As shown in figure 2.4, the industrial waste sources were taken from several sectors which included; chemical, petrochemical, plastic products, food and beverages, textile apparel, electric and electronic products, fabricated metal, paper and paper products, wood and products of wood, and basic metal and non-metallic mineral products. The average composition of the waste from various industries in Malaysia shows that the highest components were plastics at 39.10% and paper at 35.10%. Food waste has contributed only 6% of the total waste (JPSPN, 2013).

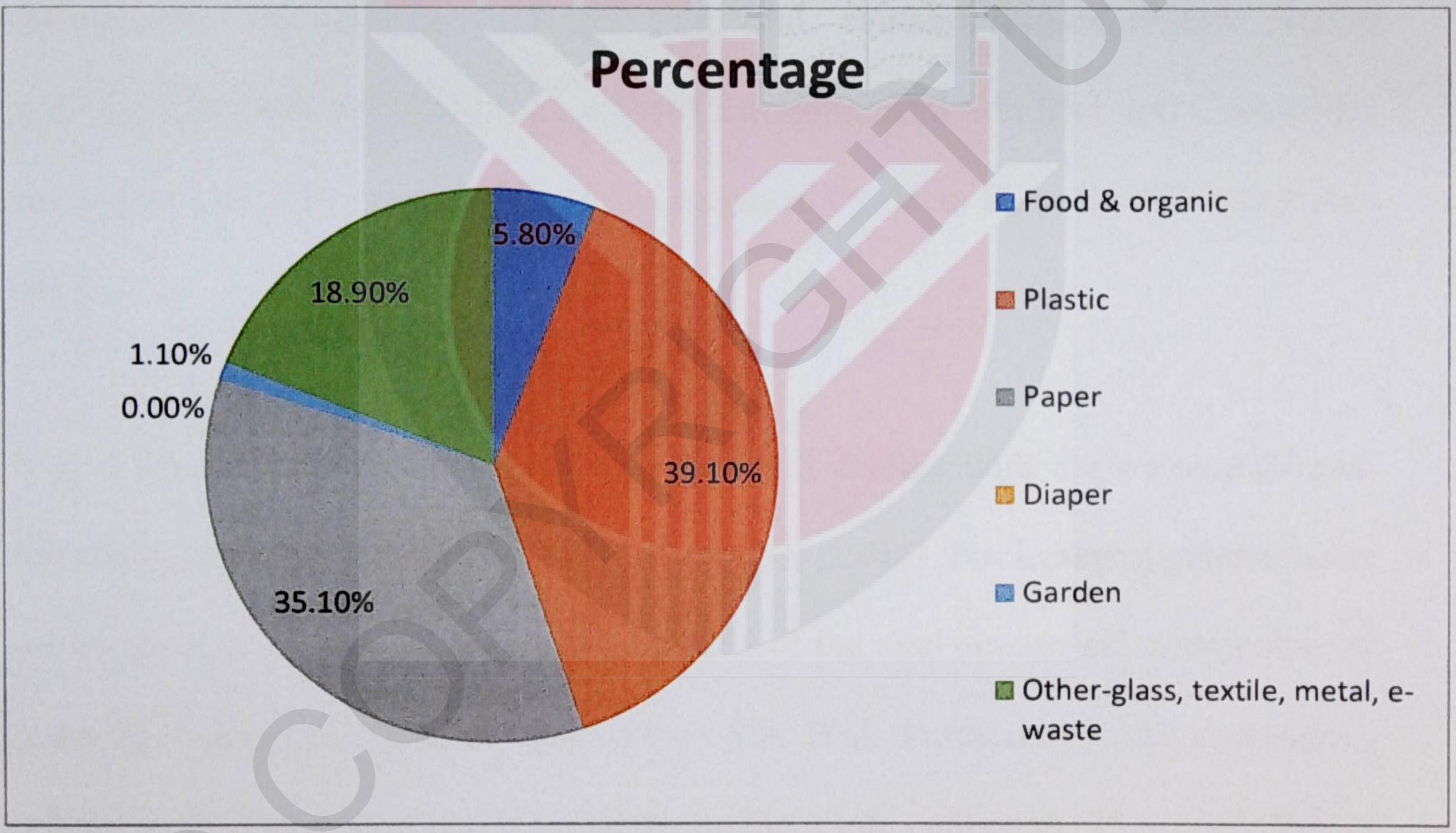


Figure 2.4: Average composition of industrial waste in Malaysia (JPSPN, 2013)

2.4 Waste collection and transportation

Waste collection and waste transport is usually managed by the private concessionaries as to reduce the financial pressure on local government (Nadzri & Larsen, 2012). Furthermore, the privatising process has been conducted through a concession agreement between the federal government and three private companies which is Environmental Idaman Sdn Bhd, Alam Flora Sdn Bhd and SWM Environment Sdn Bhd. The private concessionaries were conducted based on different region of states. For instant, the northern region (Kedah, Perlis) was managed by Environmental Idaman Sdn Bhd, southern region (Johor, Negeri Sembilan, Melaka) was managed by SWM Environmental Sdn Bhd, and Central and east region (KL, Putrajaya, Pahang) was managed by Alam Flora Sdn Bhd (Mutalib, 2013).

The private collection companies are still dealing with the waste collection services based on long term contract (Jereme et al., 2015). For instance, private waste contractors are responsible for more than 50% of the total amount of waste collected under the consession area of Alam Flora Sdn Bhd. Furthermore, the community collection initiatives also play a main role in the waste collection. The scheduled for waste collection and collection methods are varies based on the need and the area covered. Karen et al., 2003 stated that common collection point's e.g. containers were required and the household will bring their waste in front of their house for waste collection. Apart from that, the common collection method in Malaysia for individual houses and link houses is door to door method.

2.5 Waste recycling in Malaysia

Paper, plastics and bottles are the types of recyclables materials generated in Malaysia, but out of these very little of the waste is recycled (Jereme et al., 2015). However, the rate of recycling has been increased with the enlightenment campaign and drastic measure taken by the government since the launching of first official recycling program in the peninsular Malaysia in 1993. In December 2000, the Ministry of Housing and Local Government (MHLG) has re-launched the recycling program to make a different by encouraging the public participation in the program. The MHLG had engaged the local public relation company to carry out the productions of billboards, posters, pamphlets, and commercial advertisement to make the program interesting and appealing to the public. The concept of 3R (Reduce, Reuse, Recycle) approach has been used in Malaysia as an alternative to reduce the disposal of waste in the landfills (Salim et al., 2018). Moh & Manaf (2014) revealed that the 3R concept is necessary to reduce the disposal of waste disposed in the landfill. Waste recycling posed a difficult challenge to developing country because of high cost waste recycling facility. There is low level of recycling rate in developing countries either because of ignorance or apathy towards recycling (Ko Chi Wai, 2007). Table 2.3 shows the household recycling rate by region in Malaysia (JPSPN, 2013)

Recycling can reduce the amount of energy required to produce (as compared to produce with virgin inputs) and can leads in reduction of GHG emission to the atmosphere (U.S EPA, 2009). It has shown that, recycling has lower GHG emissions than other waste management options except for source reduction. When the recyclable material is recycle, it is used in place of virgin inputs in the manufacturing process, rather than being disposed in the landfill. Recycling process are divide into two processes which is closed loop recycle and open loop recycle. Closed loop recycle is considered as a process in making the same product by using same virgin material (e.g., newspaper is recycled into new newspaper). However, open loop recycle is considered as a process in making new product by using the different virgin material (e.g., personal computer is recycled into a new product other than themselves) (U.S EPA 2009).

Table 2.3: Household recycling rate by region in Malaysia

Region	Overall recycling rate
Northern	9.0%
Klang valley	10.0%
East Coast	11.4%
Southern	10.6%
Sarawak	9.4%
Sabah	2.9

Source : JPSPN, 2013

2.6 Waste incineration

According to Knox & Andrew (2005), Incineration is a waste treatment process that involves the combustion of organic materials. The fast growing economy in Malaysia and the increased focused on the environmental affects have increased the waste collection in this country and thus the need for incinerator. Incineration is one of the best alternatives in treating municipal solid waste in Malaysia due to various constraints such as limited landfill, immature recycling and biological treatment infrastructures (Haliza, 2013). Currently, there are five small scales of incinerator in Malaysia with the capacity of less than 100 tonnes each in Pulau langkawi (100tonnes/day), Pulau Tioman (10 tonnes/day), Pulau Pangkor (20 tonnes/day), Cameron Highlands (40 tonnes/day) and Labuan (60 tonnes/day) (Zi Xiang, 2012). However, the number of incinerator is still lacking in our country due to the waste generation rate in big cities is continuously rising up every year because of the uncontrollable consumption owing to the increasing population, the attitude towards shopping and high living standards (Haliza, 2013).

A study revealed by Ramboll (2006) shown that the important role of incineration in reducing waste volume and increasing economy with energy recovery. The incineration of solid waste has the possibility to reduce the volume of waste by 80% to 85% and the volume (already compressed in garbage trucks) by 95% to 96%. However, the volume of the waste left depending on composition and degree of recovery materials such as metals from the ash for recycling. The incineration of the waste can highly reduce the land use as the left waste need to be disposed in the landfill only 10% of ashes. Furthermore, incineration of waste is environmentally benefits as it can reduce the emission of carbon to the atmosphere, avoidance of land contamination, higher energy recovery, outputs of ashes in inert form, chemically stable without odour and only need minimum are of land (zi Xiang, 2012).

2.7 Waste composting

Composting is defined as a process decomposition of organic matter by several microorganisms under certain condition which is moisture, aerobic or anaerobic to produce compost's product which is a stable, low in moisture and free from pathogen. For instance, composting is one of the best method to manage food waste as it cost effectively and environment friendly which is the most important is can reduce the pollution and also can provide an income for the products (Aminah et al., 2016).

Composting techniques are divided into two main types which is aerobic and anaerobic composting. Aerobic composting is the decomposition process which occurs in the condition presence of oxygen. It will produce the stable organic end product with carbon dioxide, ammonia, water, heat and humus. It also has less risk of phytotoxicity. The heat generated from the aerobic composting will accelerate the breakdown of organic matter. However, the nutrients from the organic matter will be lost during this process. The anaerobic composting processes occur without the presence of oxygen. The process will produce strong odour and has the risk of phytotoxicity. The decomposition process of organic matter will produce low temperature and the nutrient will retain in the products. However, the anaerobic process will take longer duration to produce mature compost compared to aerobic process (Aminah et al., 2016).

There are several food waste methods including passive composting or piling, aerated static piles, windrows method, bins method, in-vessel systems, and vermicomposting (Risse & Faucette, 2013). Siti Aminah et al., 2016 stated that the other method of composting includes shredding and frequent turnings, usage of cellulolytic cultures, aerated static pile composting, rectangular agitated beds, silos, use of mineral nitrogen activator and usage of effective microorganisms. For example, the technique of vermicomposting used red worms to eat all the organic material during the composting process, while technique using of mineral nitrogen activator are adding the nitrogen fertilizer into the compost process.

2.8 Landfill in Malaysia

As mentioned by Fauziah & Agamuthu (2012), landfilling is the oldest, most common and preferable disposal activity considering the social, economic aspects in developing country. However, it is the least preferable method of disposal based on waste management hierarchy. Depending on landfill as the main disposal method is a critical issue because there were no technologies available to avoid the entire unwanted residue from the waste sector and no endowment for zero waste. According to Goh Ban Lee (2011), Malaysia is facing the serious problem related to landfilling practises like used beyond its capacity, overflowing of landfill site, no facility for venting gas, no leachate treatment, unsuitable of landfill site and shortage of land. However, the government has taken initial steps to overcome the problem by taking initiatives like privatization of landfill operation for a better management. For instance, Alam Flora has been appointed by government to manage Kundang landfill at Selangor and Idaman Bersih has been appointed to manage Pulau Burung Landfill in Penang. Through the entire initiatives, some of the landfill has been upgraded to level 3 and level 4 facilities. According to World Bank (199b), level 0 landfill is literally open dumpsite, level 1 landfill is controlled tipping, level 2 landfill equipped with bund and daily cover, level 3 facility of landfill is equipped with leachate circulation system and the level 4 facility is equipped with leachate treatment facilities.

Landfills are widely used in Malaysia as the main disposal method as it low cost and easy to manage. Landfills in Malaysia are divided into two different types which is sanitary landfill (fully equipped landfill with environmental measure) and non-sanitary landfill (less environmental control measure). Most of the landfills in Malaysia are non-sanitary landfill (Johari et al., 2012). Table 2.4 shows the number of operating sanitary and non-sanitary landfills in Malaysia.

State	2015			2016			2017		
	Sanitary	Non-sanitary	Total landfill	Sanitary	Non-sanitary	Total landfill	Sanitary	Non-sanitary	Total landfill
Johor	1	13	14	1	12	13	3	9	12
Kedah	1	6	7	1	6	7	3	4	7
Kelantan	0	11	11	0	11	11	0	11	11
Melaka	1	0	1	1	0	1	1	0	1
Negeri Sembilan	1	7	8	1	5	6	2	3	5
Pahang	2	14	16	3	11	14	8	4	12
Perak	0	16	16	0	17	17	3	13	16
Perlis	0	1	1	0	1	1	1	0	1
Pulau Pinang	1	1	2	1	1	2	1	0	1
Sabah	1	18	19	1	18	19	1	21	22
Sarawak	3	46	49	3	46	49	3	43	46
Selangor	3	5	8	4	4	8	3	2	5

Terengganu	0	9	9	0	9	9	4	6	10
W.P Kuala Lumpur	0	0	0	0	0	0	0	0	0
W.P Labuan	0	1	1	1	0	1	1	0	1
Total	14	148	162	17	141	158	34	116	150

Source: JPSPN, 2017

Table 2.4: Number of operating sanitary and non-sanitary landfills in Malaysia

2.9 Polluter Pay Principle

Waste management policies include a broad range of complementary measures such as economic, regulatory, educational and informative instruments (Beukering et al., 2009). The main objective of an economic instrument is to persuade waste producers to change the main disposal method of solid waste from landfill or incineration towards material recovery, in order to optimise the use of resource, while contributing to the costs of the waste management service (Morlok et al., 2017). The economic instrument can be implemented either in national or regional policies such as through waste disposal taxes (landfill tax, incineration tax, product levies, etc.), waste pricing (unit based, differential rates, variable rates, pay as you throw, etc.), deposit refund scheme, tradable permits, extended producer responsibility, recycling subsidies, and value-added tax (VAT) exemptions for repair and recycling activities (Morlok et al., 2017)

In the municipal solid waste management context, "Pay –As-You –Throw" (PAYT) approach is an economic instrument that applies the "polluter pays" principle at the municipal level by charging inhabitants according to the amount of waste they send for third party management (Bilitewski et al., 2004). Dijkgraaf & Gradus (2004) stated that PAYT also known as unit pricing and differential and variable rate or variable fee charge systems. Polluter Pay Principle (PPP) is a waste management scheme and PAYT is one of the approaches applied under this principle (Morlok et al., 2017).

PAYT is a powerful instrument that was used by local authorities to support and optimize waste management policy and improve the situation of urban waste generation by increasing waste separation and recycling among the consumer (Bilitewski, 2008). As mentioned by Skumatz (2008), PAYT systems also known as variable rates programs or user pay, ask households to pay more if they put out more garbage for collection. The polluter-pays principle stands as an international guideline for environmental policy specifying that the person or firm who damages the environment must bear the cost of such damage (Luppi, Parisi & Rajagopalan, 2012).

The implementation of PAYT in the United States has led the diversion of perhaps 6.5 million tons of municipal solid waste (MSW) per year (4.6-8.3 million) that would otherwise have been landfilled (Skumatz & Freeman, 20066a). The amount of the diversion of MSW is based on a combination of the tons diverted for recycling, composting and source reduction. In Korea, the waste allocations have shifted from 1990 to 2008 due to implementation of the unit pricing system. 81.6% of the total waste has been disposed in the landfill in 1994 with low recycling rate at 15.36%. However, after implementation of unit pricing system, the recycling rate has increased steadily up to 59.8% in 2008 while landfill has decreased down to 20.3% (Korean Ministry of Environment, 2009). The volume of the MSW stays around 50,000 tons and it does not increase although the Korean economy has grown up (Korean Ministry of Environment, 2009)

2.10 Environmental issues related to waste disposal

2.10.1 Greenhouse gases emission

Solid waste management is the biggest environmental issues in the developing country such as Malaysia. It is because, Malaysia highly dependent on landfilling activities as the main disposal method for solid waste that are continuously increase its generation. The problems in managing the issues related to solid waste are complex due to various factors such as the amount and composition of waste generated, rapid expansion of urban areas, rapid technological advancement and funding issues (Latifah & Yiing, 2016). Furthermore, Hassan et al (2016) have stated that solid waste management (SWM) is a global challenge in economically developing country due to rapid growing populations, life style changes, rising community living standards, and will cause increasing solid waste generation.

Municipal solid waste is a significant contributor to greenhouse gas emissions through decomposition and life-cycle activities processes. The majority of these emissions are a result of landfilling, which remains the primary waste disposal strategy internationally (Lou, 2009). In particular the disposal of waste in landfills generates methane that has high global warming potential. Effective mitigation of greenhouse gas emissions is important and could provide environmental benefits and sustainable development, as well as reduce adverse impacts on public health (Papageorgiou, 2009).

The greenhouse gases produced by human activities have been predominating over those of natural origin (Hansen, 2004). The waste sector is a significant contributor to greenhouse gas (GHG) emissions accountable for approximately 5% of the global greenhouse budget (IPCC, 2006). This 5% consist of methane (CH4) emission from anaerobic decomposition of solid waste and carbon dioxide (CO2) from wastewater decomposition (IPCC, 2006).

Landfills are among the nation's largest emitters of methane, a key greenhouse gas, and there is considerable interest in quantifying the surficial methane emissions from landfills (Mackie, 2009).The greenhouse gases emissions related to landfilling are mainly due to methane (CH_4) and carbon dioxide (CO^2) present in the biogas produced by anaerobic bacteria using as carbon source the biodegradable carbon contained in the waste (IPCC,2007a). Methane is regarded as one of the most important GHGs because its global warming potential has been estimated to be more than 20 times of that of carbon dioxide and atmospheric methane concentration has been increasing in the range of 1–2% per year (IPCC, 2007a).

The atmospheric concentration of methane has increased by 151% since 1750 and its concentration continues to increase (IPCC,2007a). Furthermore, methane is an explosive gas in concentrations between 5 and 15 percent in air. There are two life stages in a landfill, its operating stage, where municipal solid waste (MSW) is being disposed of, and its closed stage, where storage capacity is reached. Operating landfills emits more CH4 than closed landfills since the major part of degradation occurs in the first few years following disposal with decreasing emission rates with time after closure (Fourie and Morris, 2004). Following closure, a landfill continues to emit GHG, possibly for several hundreds of years (Borjesson *et al.*, 2004).

The methane and carbon dioxide emission that were released from the decomposition process of municipal solid waste in the landfill can contribute to global warming. The high concentration of GHG can cause a reduction in outgoing infrared radiation, thus the earth's climate must change in order to restore the balance between incoming and outgoing radiation. The climatic change leads to global warming of the earth's surface and the lower atmosphere as warming up is the simplest way for the climate to release the energy. The global warming can increase the temperature of the earth. A small change in temperature rise can cause many other changes such as cloud cover and wind patterns (Latake, Pawar & Ranveer, 2015). Based on complex climate models, the "Intergovernmental Panel on Climate Change" in their third assessment report has forecast that global mean surface temperature will increase by 1.4°C to 5.8°C by the end of 2100.

The global warming can increase the sea level. The sea level increase due to two different processes that occur. Firstly, the thermal expansion of seawater can cause se level to rise due to warmer temperature. Other than that, the melting water from glaciers and ice sheets of Antarctica and Greenland will increase the sea level by 0.09 to o.88 m between 1990 and 2100. The global warming can cause potential impact on human life and agricultural impact. The rise of the sea level can cause worst economic impact on low lying coastal areas and islands. For instance, it can increase the cases of beach erosion rates along coastlines, rising sea level displacing fresh groundwater for a substantial inland (Latake, Pawar & Ranveer, 2015).

Other than that, the high concentration of carbon dioxide can give a positive growth to the flora habitats. However, the negative impact of global warming may affect the atmospheric general circulation and definitely will change the global precipitation pattern. Furthermore, it will change and affect the soil moisture content over various continents. Global warming also can cause negative effects to the aquatic systems. The fish population will getting lower due to the loss of coastal wetlands. Furthermore, global warming also can give effects to hydrological cycle. Some of the regions in the world will receive high precipitation, while the others may have less. These changes will create problems for many water management systems as they have to deal with different scenarios (Latake, Pawar & Ranveer, 2015).

2.10.2 Heavy metals in leachate

Landfills give various problems to the environment in which during the operations, different kinds of hazards including gas and leachate are produced (Modin & Hanna, 2012). The problem of leachate is getting worse because of many landfills did not have appropriate bottom liner or collection system that can increase the possibility of dissipation of leachate through the landfill layer to contaminate the ground water (Kanmani & Gandhimathi, 2012). The leachate composition varies greatly depends on the characteristics of the waste dumped to the landfill.

The volume of leachate produce is affected by two factors, i.e. direct landfill moisture distributors such as rain fall, snowmelt, groundwater intrusion, initial moisture, and leachate recirculation. Other than that, it is affected by landfill moisture distribution influencers namely refuse age, pre-treatment, permeability, compaction, particle size and density (El- Fadel et al., 2002). Emineke et al., (2012) in their study revealed that the leachate from municipal landfill is genetoxic and highly ecotoxic (irrespective of its stabilisation status), and equivalent to that of industrial landfill leachate.

As studied by Agamuthu & Fauziah (2002), the negative impacts of MSW landfill to the environment cause a wide range of concern such as increase the risk of explosion, odour problem, and contamination of leachate that contain heavy metals in soil and groundwater. Sumaiya et al (2014) in their study revealed that one of the most hazardous components in leachate is heavy metals. Furthermore, landfills especially in Asia contain high concentration of heavy metals in leachate from closed and active landfills (Emenike et al., 2011). A great concern of leachate pollution in the water because it can resulting potential bioaccumulation of the pollutants (manganese, copper,zinc, iron, chromium, aluminium) in the aquatic organisms and humans (Fauziah, Emineke & Agamuthu, 2013) .

Landfill leachate is one of the major anthropogenic heavy metal sources in nature. The leachate pollution potential or ecotoxicology is based on the metallic element such as zinc, chromium, copper and lead (Oygard et al., 2007). The risk of heavy metal contamination is getting higher due to leachate discharged that contain heavy metal and enter the ecological pathway. The leachate containing heavy metal will enter the food web and are ingested into our bodies through water and food consumptions. The heavy metals are persistent and do not break down in the body. it only transforms from one oxidation or complex element to another element (Agarwal et al., 2010). The bioaccumulation of heavy metals in body will cause chronic health effect.

2.11 Health impacts

According to Monisha et al., (2014), the exposure of heavy metals has proven to be a major threat and will cause several health risks associated with it. Cadmium is one of the heavy metals that harm human body. The route of exposure to cadmium is through inhalation and ingestion and can cause acute and chronic intoxications. The production of cadmium from the landfill will remain in soil and sediments for several decades. The plant will take up and accumulate the cadmium and will enter the food chain that can ultimately reach to the human body. Han et al., 2009 stated that cadmium is predominantly found in fruits and vegetables due to its high rate of soil to plant transfer. The ingestion of food that contain cadmium into the body will cause the concentration to increases 3,000 folds when it binds to cysteine-rich protein such as metallothionein. The cysteine-metallothionein will cause liver toxicity and will circulates to the kidney and accumulated in the renal tissue causing nephrotoxicity (Monisha et al., 2014). The cadmium has the ability to bind with cysteine, glutamate, histidine, and aspartate ligands that can lead to iron deficiency (Castagnetto et al., 2002). Cadmium exposure can cause bone damage, renal dysfunction, hypercalciuria, stomach irritation, and kidney disease (Bernard, 2008).

Matsumoto et al., (2006) revealed that the chromium compound can cause DNA damage in many different ways which can lead to formation of DNA adducts, chromosomal aberrations, alterations in replication, transcription of DNA and sister chromatid exchanges.

The exposure of lead can cause toxicity in living cells by following ionic mechanism and oxidative stress. The imbalance between the production of free radicals and the generation of antioxidants to detoxify the reactive intermediates or to repair the resulting damage can give rise to oxidative stress in living cells (Monisha et al., 2014). The heavy metal attacks on the cell can cause structural damage to cells, proteins, nucleid acid, lipid and membranes, that can result in oxidative stress situation in cellular level (Mathew et al., 2011). The presence of lead in the body can cause the level of reactive oxygen species (ROS) increases and the level of antioxidant (glutathione) decreases. Toxicity of lead can induce acute and chronic health effect. The acute health effects are loss of appetite, headache, hypertension, abdominal pain, fatigue, hallucinations and vertigo. Furthermore, the chronic health can result in autism, dyslexia, muscular weakness birth defect, brain damage, kidney damage and can cause death (Martin & Griswold, 2009).

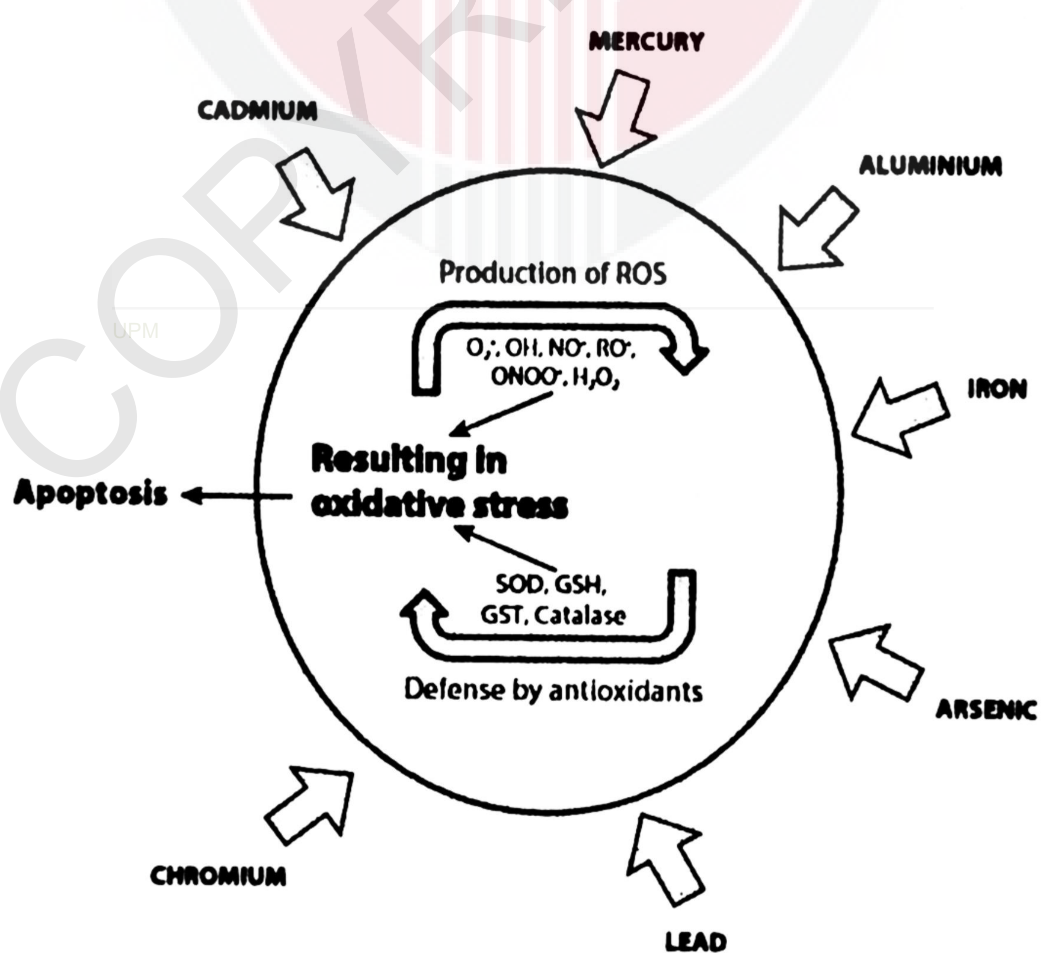


Figure 2.5: The attack of heavy metals on a cell (Monisha et al., 2014)

Alam and Ahmade (2013) has documented in their study that the disposal of solid waste can give a serious health hazard and increase the risk of infectious disease and environmental pollution. The disposal of solid waste can cause soil, air and water pollution which provides breeding area to the biological vector that can increase disease infection such as diarrhoea, dysentery, food poisoning, leptospirosis and bacterial infection (Pradyumna, 2013). The composition of the gas released from the landfill are varies such as methane, carbon dioxide and nitrogen dioxide are the main factor in polluting the environment and lead hazardous health effect(cancer and birth problems). The population exposed to the pollutants via inhalation of the air borne emission (Maheshwari, Gupta, Das, 2015). Furthermore, the International Agency for Research on Cancer (IARC) has revealed that heavy metal such as cadmium is carcinogenic to human and classified under Group 1 carcinogenic. Environmental pollution of waste associate with waste dumping can give short and long term effect on health (Mattiello et al., 2013). Ashworth et al., (2014) have revealed that the short term health effects are respiratory infection, asthma and congenital anomalies. Furthermore, the short term exposure to the pollutants from the landfill can cause eye and respiratory irritation, headache, stress, anxiety, dizziness and nausea (Kah et al., 2012). Carpenter et al., (2008) in their study had shown that long term of pollutant exposure from the landfill by product can cause cancer, chronic respiratory, cardiovascular disease and nerves disorder.

CHAPTER 3

METHODOLOGY

3.1 Study Design

This is a cross sectional study design to determine the potential contribution of polluter pays principle (PPP) on reduction of environmental pollution and health risk for municipal solid waste (MSW) in Klang.

3.2 Description of study area

The study area was in Klang Selangor since it is the major waste generator in the country with 1.35 kg/capita/day or 9702 metric tonne/day (JPSPN, 2013). Based on 2010 census, the total population in Klang area was 861,189 (changed +2.36% every year) with area covered 672 km^2 and density of $1374/km^2$. The waste collection in Klang is working at three times per week for domestic and household waste and the collection for garden and illegal dumping waste was collected 12 or 36 times in a month respectively. The collected waste was disposed in Jeram sanitary landfill (Majlis Perbandaran Klang, 2018). The Jeram sanitary landfill is located in Tuan Mee Estate, Jeram, District of Kuala Selangor, Selangor Darul Ehsan. Jeram sanitary landfill is managed by World Wide Landfill (P) Ltd under jurisdiction of Selangor State Government.The Jeram Sanitary landfill covered 160 acres area size with capacity 2500 ton/day. The operation of Jeram Sanitary landfill started in 1st January 2007 and expected end of operation in 31st December 2031.

This sanitary landfill is well planned and engineered to prevent the risk of environmental contaminations.

Jeram sanitary landfill equipped with gas wells, gas well system, gas piping system, gas delivery unit, leachate collection system etc. The waste that has been sent to Jeram landfill includes domestic waste except non sanitary waste, food waste from restraints and canteen waste, paper and cardboard, polythene/polystyrene, market waste, cans, glasses or bottles, builders rubble except demolition waste, green waste except tree trunks, wood pallets, general litter, confiscated, rejected or expired food and drink waste, and expired/damage non-hazardous product, and any waste subjected to Department Of Environment (DOE) consideration can be disposed to landfill.

Figure 3.1: The location of study area, Klang was highlighted in the map.

3.3 Data analysis

The secondary data of the volume of municipal solid waste (MSW) were collected from Majlis Perbandaran Klang (MPK) from 2011 to 2017. The datasets obtained the volume of solid waste that has been disposed in Jeram landfill by month and year. The fraction of MSW were separated into sources of waste (i.e. household, commercial, and institutional, and industrial) and compositions (food and organic, plastics, paper, diapers, garden, etc) and the percentage were estimated based on literature data on the fractions of MSW from National Solid Waste Management Department (JPSPN, 2013). The collected data was analysed by using mathematical formula. This study used excels to estimate the emission of green-house gases (GHG), non-methane organic compound (NMOC) and health risk, the production of leachate and heavy metal contain by using adopted mathematical equation.

3.3.1 Greenhouse Gases (GHG) Emission

i. Methane gases emission from landfill

The methane gases emission was calculated based on the waste deposited in the landfill by using equation (1) and (2).

$$DOC = \Sigma\,(0.15F + 0.20G + 0.40P + 0.43W + 0.24T + 0.24D + 0.0O) \quad \text{eq. 1}$$

The degradable organic carbon (DOC) was calculated by using equation 1 where the default carbon content value for food waste, garden waste, paper and tetra pak, wood, textile, diapers and other waste (rubber, leather, plastics, metal, glass) is 0.15, 0.20, 0.40, 0.43, 0.24, 0.24 and 0.0 (IPCC, 2006). F is the fraction of food waste in MSW, G is the fraction of garden waste in MSW, P is the fraction of paper waste in MSW, W is the fraction of wood in MSW, T is the fraction of textile in MSW, D is the fraction of diapers in MSW and O is the fraction of other waste in MSW (JPSPN, 2013). Thus, methane gases emission will be calculated by using equation 2:

$$CH4\ emission\ (tonne) = \Sigma i\ (MSWT \times MSWF \times MCF \times DOC \times DOCF \times F) \times \frac{16}{12} \qquad \text{eq. 2}$$

MSWT is the total of municipal solid waste disposed in the landfills (tonne). The municipal solid waste fraction (MSWF) is 0.8. According to Dong et al., 2010, Malaysia disposed 80 of waste to the landfills. MCF is the methane correction factor and it is ranged from 0.4 to 1.0, value 0.6 can be used for Malaysia landfill (Anwar, Saeed, Haslenda, Habib, & Mat, 2012). The degradable organic carbon (DOC) will be calculated by using equation 1. The degradable organic carbon fraction (DOCF) is 0.77 (Anwar et al., 2012). The default value for Fraction (F) is 0.5 where landfill approximately generates 50 percent of methane gases (IPCC, 2006).

ii. Carbon Dioxide Equivalent Emission

Carbon dioxide equivalent was calculated by using equation 3;

$$\textit{The total carbon dioxide equivalent (tonne)} = \Sigma\,(TCH4 \times 25) \qquad \text{eq. 3}$$

The total carbon dioxide equivalent (TCO_2 –eq) is defined as 100 year global warming potential (GWP) factors by multiplying the estimated total of CH_4 emission (TCH4) by 25 as methane gases has 25 times GWP than CO_2 (IPCC, 2006).

3.3.2 Leachate Production

Leachate production was calculated by using equation 4 (KPKT, 2015);

$$\textit{Volume of leachate} = \Sigma\,(MSWT \times 0.21) \qquad \text{eq. 4}$$

The volume of leachate (VL) was calculated in (m^3) unit. The total municipal solid waste (MSWT) is the total of waste disposed in the landfill (tonne) and 0.21 refers to one tonnes of waste will generate 0.21 m^3 of leachate (KPKT, 2015).

3.3.3 Heavy Metal in leachate

The quantity of heavy metal released from the leachate was calculated by using equation 5;

$$Heavy\ metal\ quantity = \Sigma h\ (VL \times ch) \qquad \text{eq. 5}$$

The heavy metal quantity (HQ) was calculated in kg per year (kg-year) unit, h refer to the type of heavy metal that were calculated in this study such as cadmium, chromium, copper, lead, zinc. VL is the total volume of leachate produced m^3 calculated from equation 4. The concentration (C) is the average of heavy metal concentration (kg-m^3) in the landfill leachate which the average value from a case study of Malaysia landfill leachate characteristics was used to estimate the emission per year(Cadmium = 2.00E-06; Chromium = 6.00E-06; Copper = 5.00E-06; lead = 1.50E-05; Zinc = 1.50E-05) (Agamuthu & Fauziah, 2010).

3.3.4 Non-Methane Organic Compound (NMOC) Emission

The landfill gas constituents of non-methane organic compound were calculated by using equation 6 (U.S EPA, 2005);

$$NMOC\ emission = \Sigma p\ (1.82 \times TCH4 \times (CP/10\hat{}6) \qquad \text{eq. 6}$$

The NMOC was calculated in m^3 per year (m^3-year) unit. The emission of non-methane organic compound was calculated based on the total volume of methane gases produced from equation 1 and equation 2. The total volume of TCH_4 (tonne) was converted to m^3, which 1 tonne= $0.42m^3$. The P refer to the type of NMOC that were considered in this study as shown in table 1. The multiplication factor of 1.82 was used in the calculation assuming that approximately 55% of landfill gas is CH_4 and 45% is CO_2 and other constituent produced in the landfill. The CP is the default value for each compound P as shown in table 3.1, and the $1 \times 10^{\wedge}6$ is the conversion unit of ppmv to m^3.

Table 3.1: The default concentration of landfill gas constituents' concentration (NMOCs)

Compound (P)	Concentration (ppmv)
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 sulphide	35.5

Source: U.S EPA (1997)

3.3.5 Health risk

The health risk assessment was conducted to identify the potential health risk of inhalation exposure to non-methane organic compound from the landfill. The health risk assessment was conducted among adult men, adult women and child community in the study area. The health risk assessment was calculated by using equation 7 (U.S EPA, 2009.

$$EHEi = \Sigma i\left(\frac{Ci \times IR \times EF \times ED}{BW \times AT}\right) \qquad \text{Eq. 7}$$

The EHEi is the exposure to pollutant P (table 1). The i is the type of pollutant compound P and the Ci is the concentration of NMOC calculated from equation 6. The default value of inhalation rate (IR) for long term exposure is varies for adult men, adult women and child which 8395 m^3/ year, 7665 m^3/year and 5475 m^3/year respectively (WHO, 1994;WHO, 1999). The exposure frequency (EF) is 1 year (365 days). The exposure duration (ED) is the lifespan of the landfill which is 20 years (SWML, 2015). The average body weight (BW) for adult men is 66.56 kg, while for adult women is 58.44 kg (Mans et al., 2009). The average body weight (BW) for child of 31.8 kg will be used (U.S EPA, 2009). The averaging time (AT) for non-carcinogenic effect is equal to the exposure duration (ED), while for carcinogenic effect, the averaging time for adult men is 72.7 years, while for adult women is 77.6 years (DOSM, 2018).

The lifetime cancer risk (LCR) for carcinogenic risk was calculated by using equation 8;

$$LCR = \Sigma i\,(EHE \times URF) \quad \text{eq. 8}$$

The i is the type of pollutant a shown in table 1, the inhalation exposure (EHE) to pollutant compound P was estimated by using equation 7 and the inhalation unit risk factor (URF) was obtained from the Integrated Risk Information System (IRIS), US EPA.

The hazard quotient (HQ) for non-carcinogenic health risk was calculated by using formula 9;

$$Hazard\ Quotient = \Sigma i\,(EHE/Rfc) \quad \text{eq. 9}$$

The i is the type of pollutant a shown in table 1, the inhalation exposure (EHE) to pollutant compound P was estimated by using equation 7 and the reference dose (Rfc) for non-carcinogenic risk was obtained from the Integrated Risk Information System (IRIS), US EPA.

3.4 Scenarios of MSW disposal method

Three different scenarios of municipal solid waste (MSW) disposal method were created based on literature review. Scenario 1 consists of 70% of landfilling activity, 20% of recycling, 5% of incineration and 5% of composting activity. In scenario 2, 60% of the waste has been landfilled, 20% of recycling, 10% of incineration and 10% of the waste has been composted. In scenario 3, 50% of the MSW have been estimated landfilled, 25% of recycling, 15% of incineration and 10% has been composted. The emission from the landfill has been estimated by using mathematical equation while for recycle, incineration and composting, the avoidance of emission have been estimated by using same equation.

CHAPTER 4

RESULTS

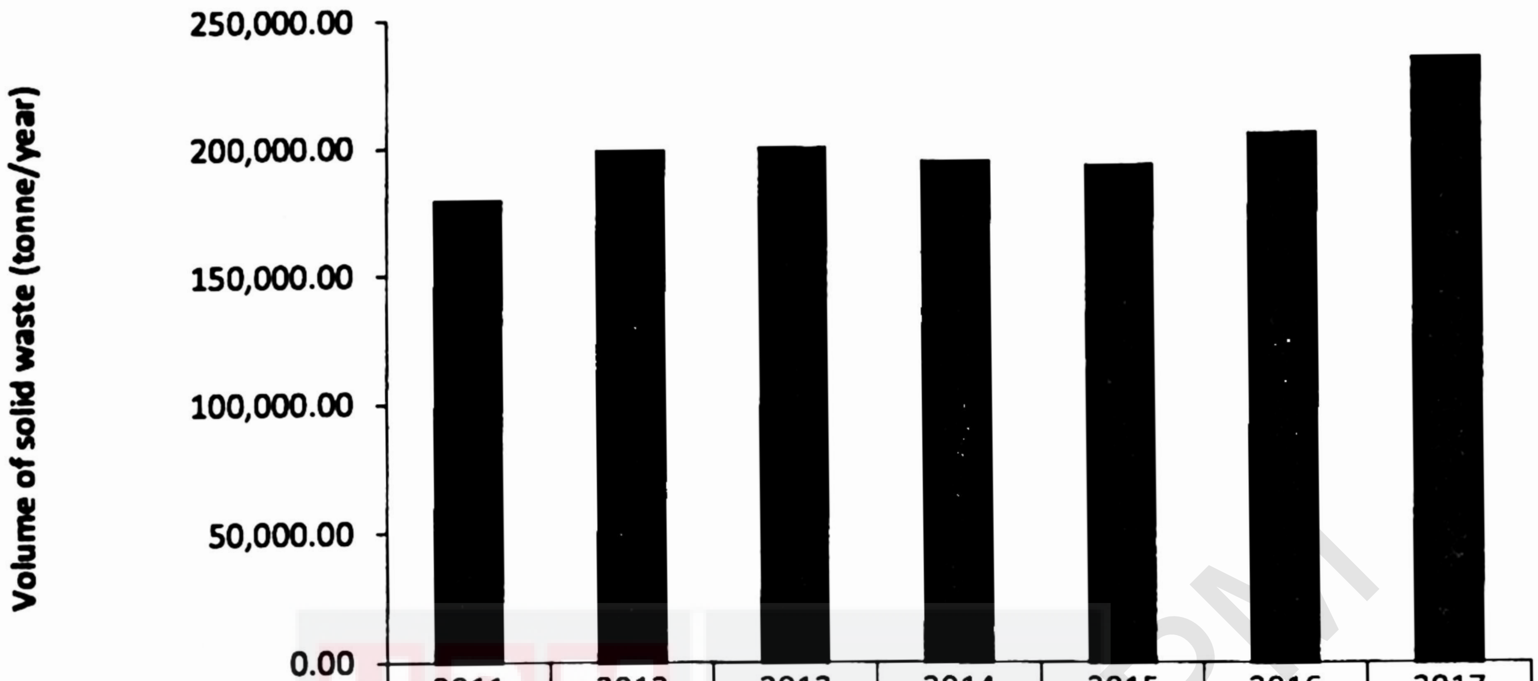
4.1 The characteristics (i.e. volume, waste composition) of solid waste disposed in landfill from 2011 to 2017 in Klang.

Table 4.1 shows the volume of solid waste disposed in Klang landfill from 2011 to 2017. The data contain the volume of waste which disposed in Jeram landfill for seven years. Based on figure 1, the volume of waste that has been disposed in Jeram landfill has shown an increasing pattern from 2011until 2017. In 2017, the data has shown the highest volume of solid waste disposed which is 231605 tonnes/year. The mean and standard deviation of solid waste disposed in 2017 were 19300.47 tonnes/year and 829.44tonnes/year respectively. While, the lowest volume of solid waste disposed was in 2011 which is 178,953.56 tonnes/year. The mean and standard deviation of solid waste disposed in 2011 were 14912.80 tonnes/year and 821.17 tonnes/year.

Table 4.1: Volume of solid waste disposed in landfills in Klang (2011-2017)

Month/year	Solid waste disposed in Jeram landfill (tonnes/year)						
	2011	2012	2013	2014	2015	2016	2017
January	14,857.88	18,141.89	17,752.05	17,509.88	16,599.55	15,592.51	21,225.60
February	13,643.14	16,073.45	15,898.69	14,435.70	14,987.17	14,661.38	17,968.04
March	14,946.38	16,816.00	16,327.37	15,255.97	16,434.41	15,058.41	19,976.91
April	14,635.24	16,395.24	16,368.96	15,898.36	15,827.07	15,032.03	18,552.34
May	14,293.91	16,908.78	16,570.20	16,425.29	15,857.25	16,013.09	19,320.88
June	14,152.00	15,620.39	15,234.33	16,566.55	16,168.70	15,260.63	18,991.99
July	15,212.24	16,466.87	17,595.90	17,116.36	16,235.22	16,917.88	18,995.75
August	15,985.03	15,383.99	16,757.09	16,024.48	16,044.96	19,371.41	19,264.74
September	14,467.28	15,378.63	16,344.14	15,686.28	15,301.52	17,548.19	18,528.3
October	14,843.00	16,001.95	16,962.07	16,689.30	15,931.96	19,087.59	19,683.97
November	15,206.47	17,000.18	16,245.01	15,728.03	16,262.52	18,844.31	19,468.67
December	16,710.99	18,183.34	17,079.04	16,842.80	16,184.52	19,688.31	19,628.44
Total per year	178,953.56	198,370.71	199,134.85	194,179.00	191,834.85	203,075.74	231,605.63
Min	13,643.14	15,378.63	15,234.33	14,435.70	14,987.17	14,661.38	17,968.04
Max	16,710.99	18,183.34	17,752.05	17,509.88	16,599.55	19,688.31	21,225.60
Mean	14,912.80	16,530.89	16,594.57	16,181.58	15,986.24	16,922.98	19,300.47
SD	821.17	941.65	699.41	852.89	457.59	1,905.46	829.44

Data from local authority (Klang Municipal Council)



	2011	2012	2013	2014	2015	2016	2017
■ Volume of solid waste	178,953.5	198,370.7	199,134.8	194,179.0	191,834.8	203,075.7	231,605.6

Figure 4.1: Total volume of solid waste disposed per year in landfills in Klang (2011-2017).

Figure 4.2 shows the household waste composition and the institutional, commercial and industrial waste composition in Klang. The household waste composition was estimated based on Klang valley household waste compositions by JPSPN (2013): Food waste (44.3%), Plastic (11.7%), Paper (9.4%), Diapers (11.7), Garden waste (5.9%), Glass (3.5%), Metal (2.2%), Textile (3.9%), Tetra Pak (1.4), Rubber (2.1%), Leather (0.3%), Wood (1.4%), Households hazardous waste (1.5%), Others (0.7%).

The institutional, commercial and industrial waste composition in Klang was estimated based on Malaysia Institutional, Commercial, and Industrial Waste Compositions by JPSPN (2013): Food waste (31.4%), Plastic (25.9%), Paper (20.5%), Diapers (0.8), Garden waste (2.8%), Glass (3.2%), Metal (4.9%), Textile (2.2%), Tetra Pak (3.0), Rubber (1.6%), Leather (0.5%), Wood (1.5%), Households hazardous waste (1.1%), Others (0.6%).

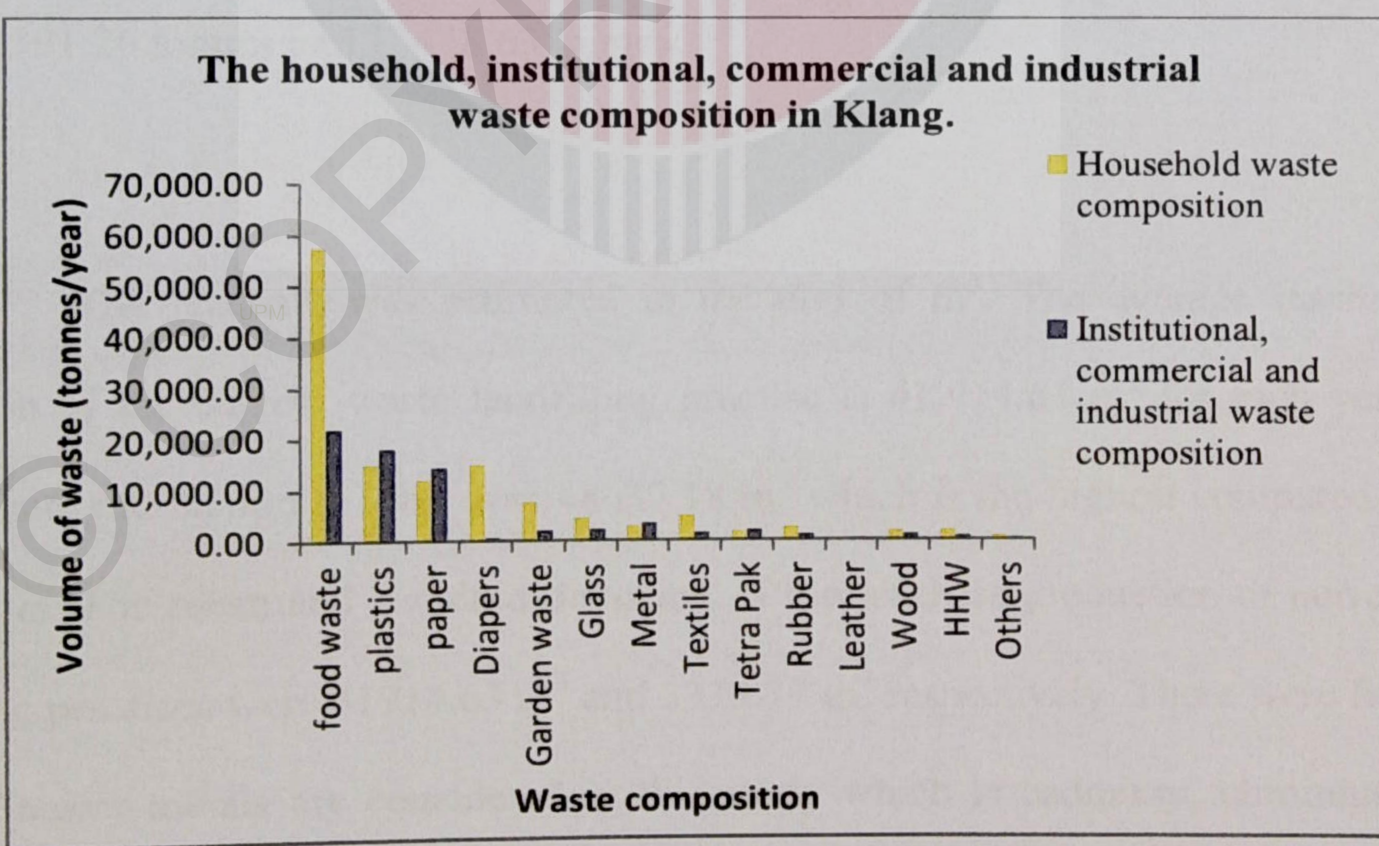
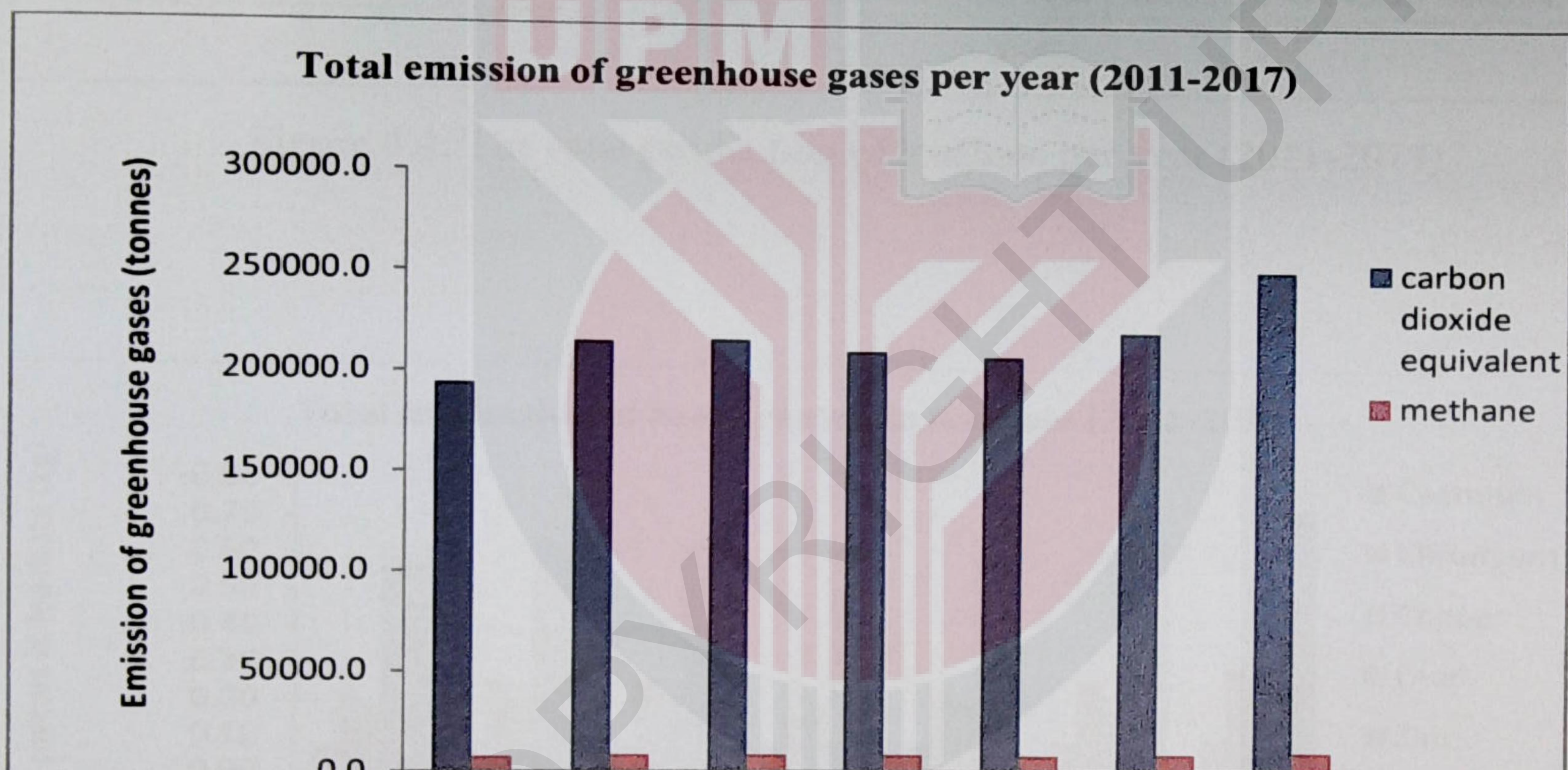


Figure 4.2: The household, institutional, commercial and industrial waste composition in Klang.

4.2 Greenhouse gases emission (CH_4, CO_2), environmental pollution and health risk of the current waste landfilling practice in the study area.

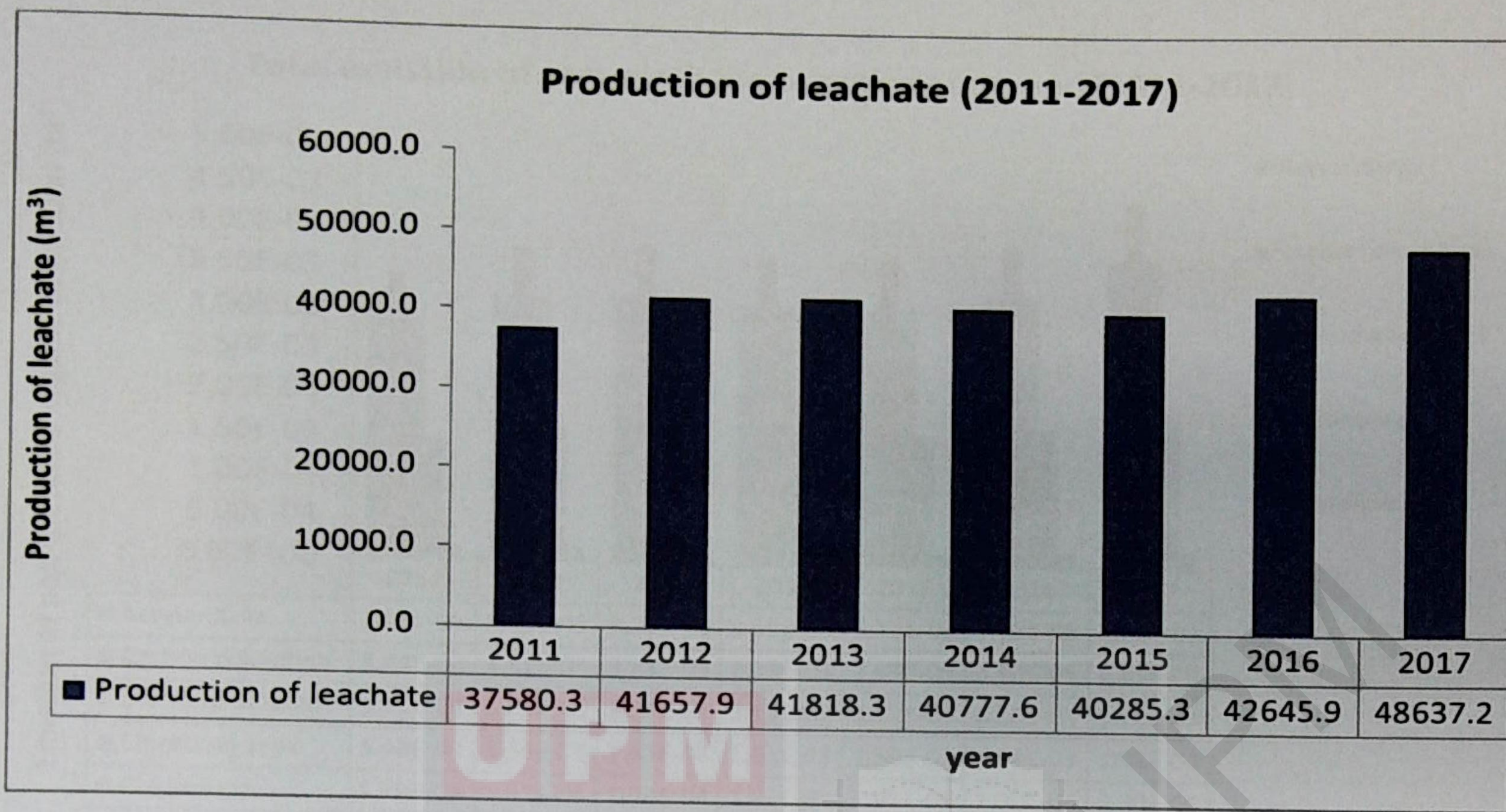
Figure 4.3 to figure 4.6 (b) shows the emission of greenhouse gases (CH_4, CO_2), leachate production, heavy metal emission in leachate and emission of non-methane organic compound (NMOC) to the environment of the total volume of waste disposed in landfill from 2011 to 2017. For greenhouse gases, the emission of methane gases and carbon dioxide equivalent are taking into consider. The highest emission of methane gases was in 2017 which is 10,043.90 tonnes. The mean and standard deviation of methane emission were 8655.65 tonnes and 697.95 tonnes. While, the lowest emission of methane gases were in 2011 which is 7760.57 tonnes. The carbon dioxide equivalent shows the highest emission in 2017 which is 251,097.56 tonnes. The mean and standard deviation for carbon dioxide equivalent were 216391.26 tonnes and 17448.63 tonnes.

The leachate was estimated in the unit of m^3. The average leachate production of the current waste landfilling practise is 41,914.63 m^3 for each year. The leachate production in 2017 was 48637.18 m^3 which is the highest compared to other years. The mean and standard deviation of the leachate production of current landfilling practices were 41914.63 m^3 and 3379.77 m^3 respectively. There were five types of heavy metals are considered in this study which is cadmium, chromium, copper, lead and zinc. Lead and zinc has shown the highest emission in leachate compared to other heavy metals. Meanwhile cadmium shows the lowest emission in leachate. The highest emission of cadmium was 9.73E-02 kg in 2017 with mean and standard deviation 8.38E-02 and 0.01 respectively. For chromium, copper, lead and zinc, the highest emission was in 2017 with the mean emission 2.51E-01 kg, 2.10E-01 kg, 6.29E-01 kg, 6.29E-01 kg respectively. For non-methane organic compound (NMOC), hydrogen sulphide was shown the highest emission compared to other gases. The total emission of hydrogen sulphide was 1.64E+00 m^3 with mean and standard deviation 2.35E-01 m^3 and 1.89E-02 m^3 respectively.



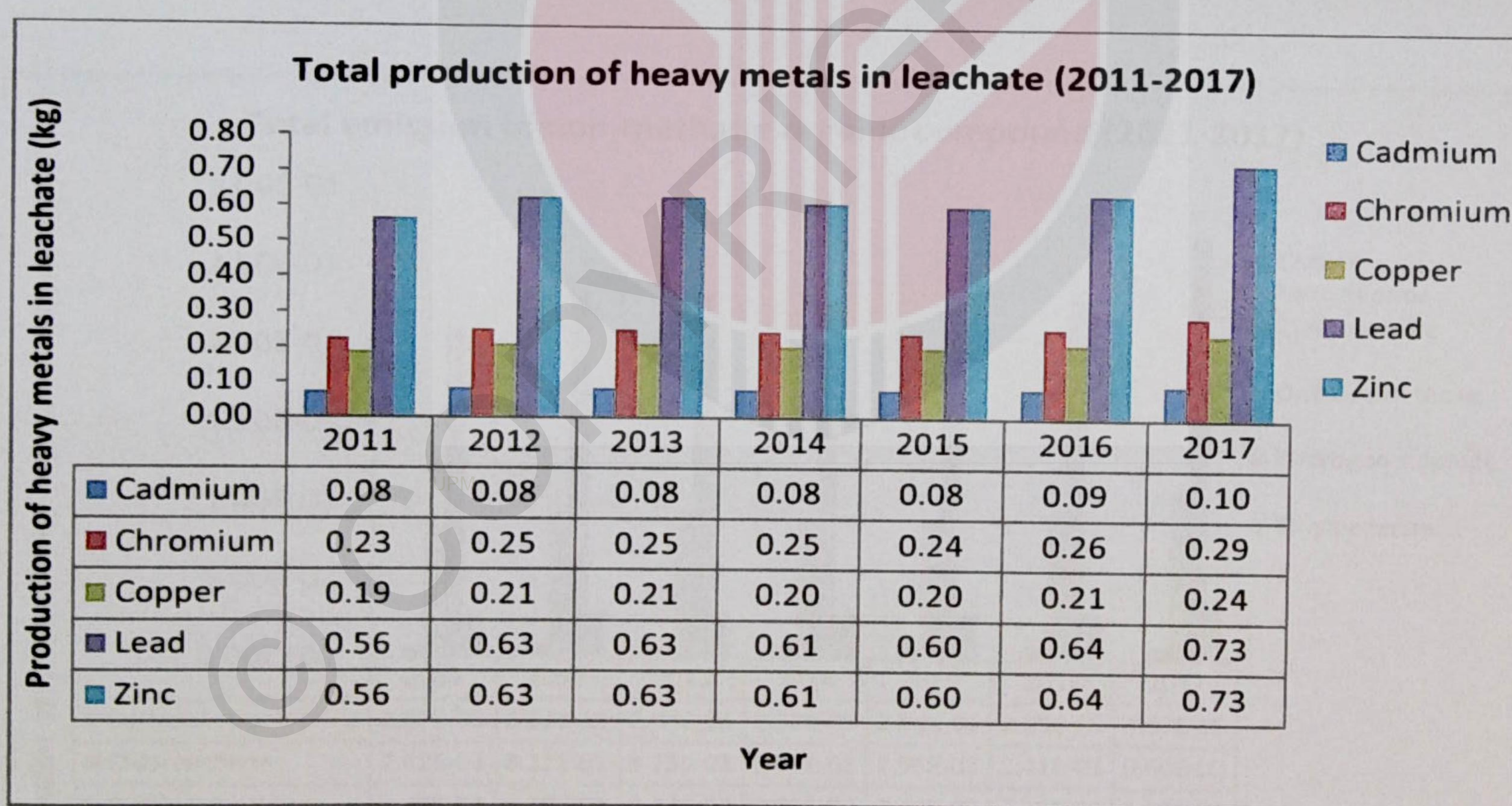
	2011	2012	2013	2014	2015	2016	2017
carbon dioxide equivalent	194014.3	215065.6	215894.0	210521.1	207979.7	220166.6	251097.6
methane	7760.6	8602.6	8635.8	8420.8	8319.2	8806.7	10043.9

Figure 4.3: The total emission of greenhouse gases (GHG) per year (2011-2017)



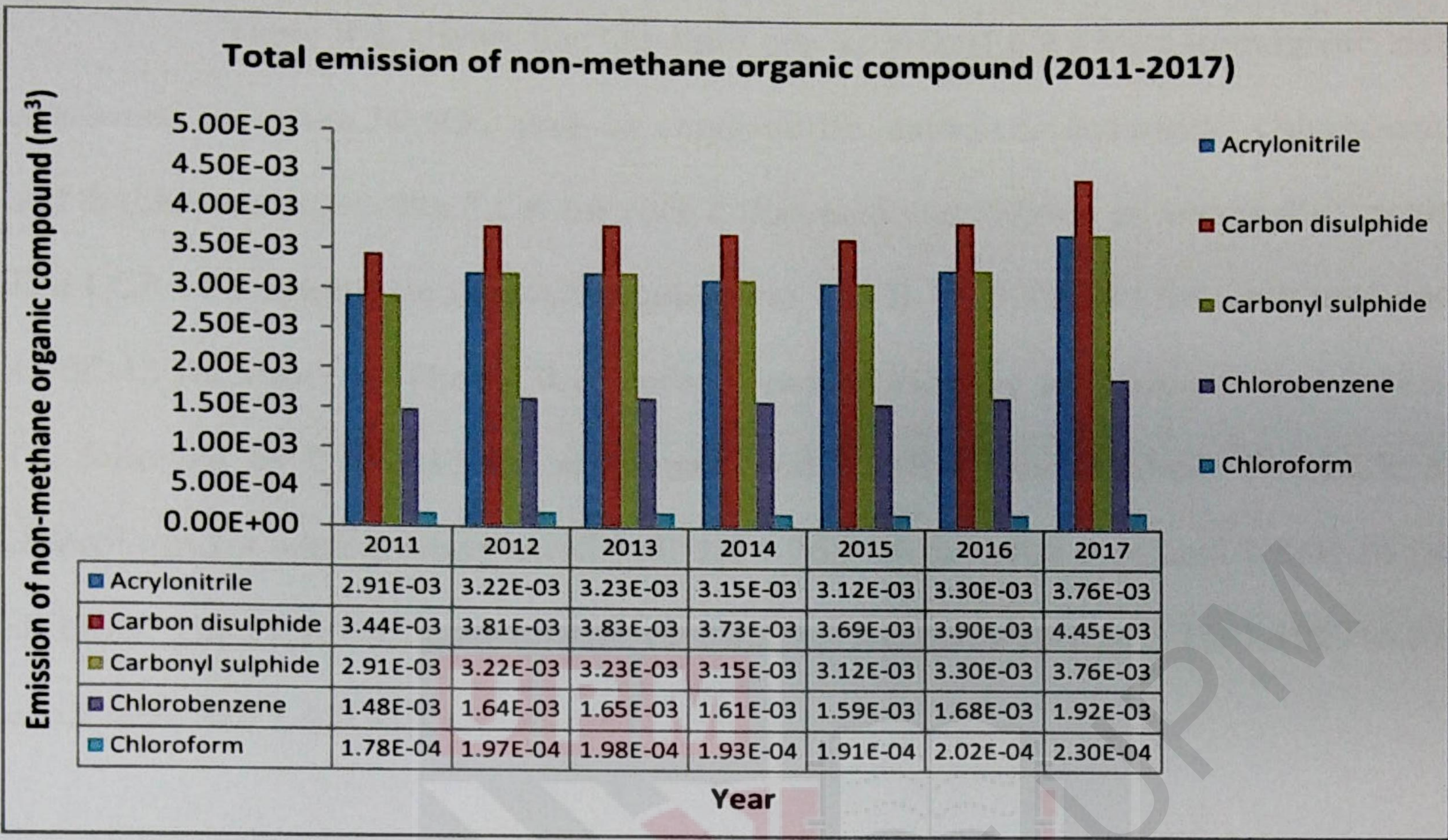
	2011	2012	2013	2014	2015	2016	2017
Production of leachate	37580.3	41657.9	41818.3	40777.6	40285.3	42645.9	48637.2

Figure 4.4: The total production of leachate per year (2011-2017)



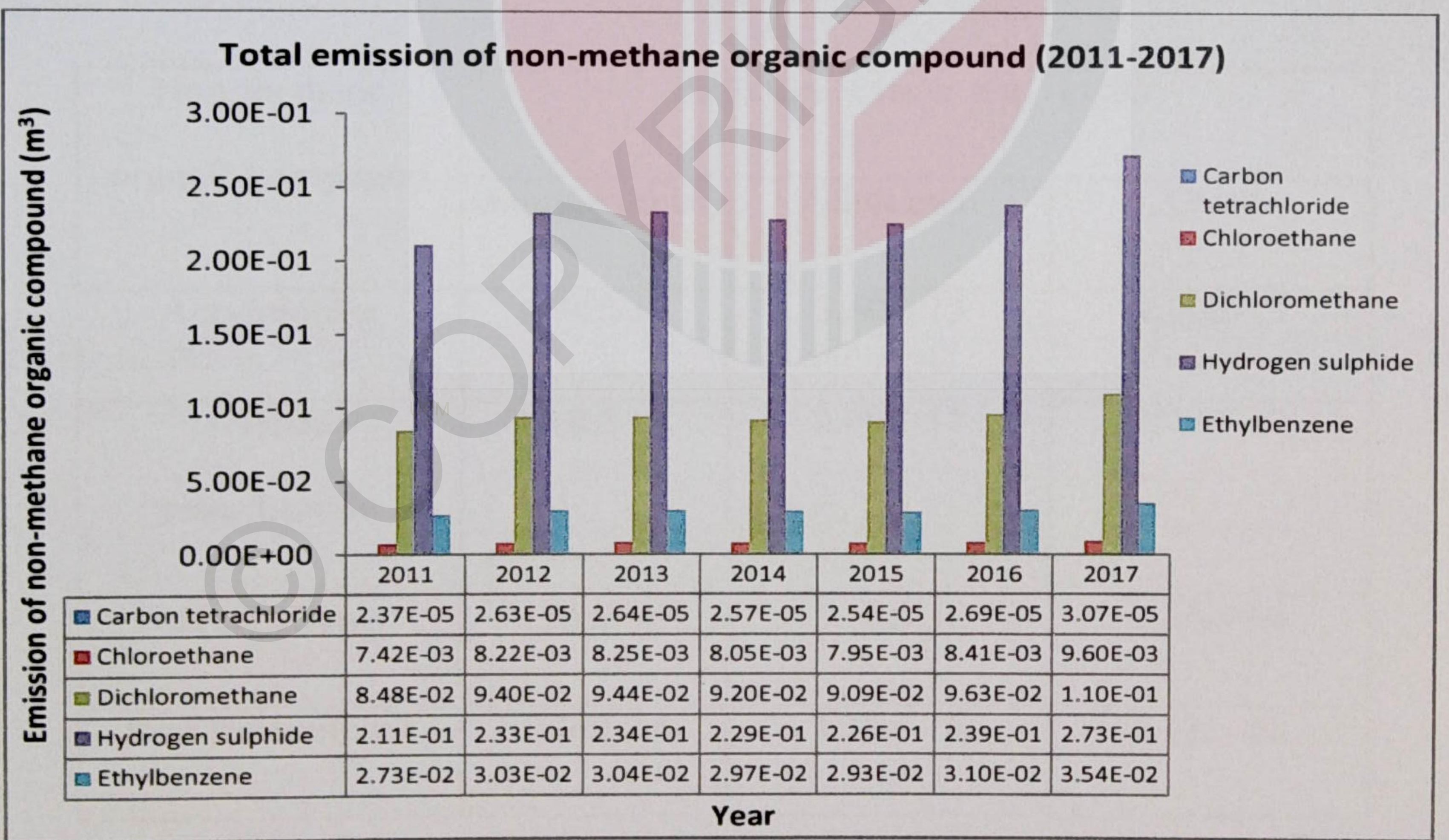
	2011	2012	2013	2014	2015	2016	2017
Cadmium	0.08	0.08	0.08	0.08	0.08	0.09	0.10
Chromium	0.23	0.25	0.25	0.25	0.24	0.26	0.29
Copper	0.19	0.21	0.21	0.20	0.20	0.21	0.24
Lead	0.56	0.63	0.63	0.61	0.60	0.64	0.73
Zinc	0.56	0.63	0.63	0.61	0.60	0.64	0.73

Figure 4.5: The total production of heavy metals in leachate (2011-2017)



	2011	2012	2013	2014	2015	2016	2017
Acrylonitrile	2.91E-03	3.22E-03	3.23E-03	3.15E-03	3.12E-03	3.30E-03	3.76E-03
Carbon disulphide	3.44E-03	3.81E-03	3.83E-03	3.73E-03	3.69E-03	3.90E-03	4.45E-03
Carbonyl sulphide	2.91E-03	3.22E-03	3.23E-03	3.15E-03	3.12E-03	3.30E-03	3.76E-03
Chlorobenzene	1.48E-03	1.64E-03	1.65E-03	1.61E-03	1.59E-03	1.68E-03	1.92E-03
Chloroform	1.78E-04	1.97E-04	1.98E-04	1.93E-04	1.91E-04	2.02E-04	2.30E-04

Figure 4.6(a): The total emission of non-methane organic compound per year (2011-2017)



	2011	2012	2013	2014	2015	2016	2017
Carbon tetrachloride	2.37E-05	2.63E-05	2.64E-05	2.57E-05	2.54E-05	2.69E-05	3.07E-05
Chloroethane	7.42E-03	8.22E-03	8.25E-03	8.05E-03	7.95E-03	8.41E-03	9.60E-03
Dichloromethane	8.48E-02	9.40E-02	9.44E-02	9.20E-02	9.09E-02	9.63E-02	1.10E-01
Hydrogen sulphide	2.11E-01	2.33E-01	2.34E-01	2.29E-01	2.26E-01	2.39E-01	2.73E-01
Ethylbenzene	2.73E-02	3.03E-02	3.04E-02	2.97E-02	2.93E-02	3.10E-02	3.54E-02

Figure 4.6(b): The total emission of non-methane organic compound per year (2011-2017)

Table 4.2 shows the life time cancer risk (LCR) for carcinogenic risk compound from the NMOC such as acrylonitrile, carbon tetrachloride, chloroform, and dichloromethane. The LCR for each compound were within an acceptable range. The LCR of acrylonitrile for adult women was 3.74E-13, 3.59E-13 for adult men and 4.90E-13 for children. The LCR of carbon tetrachloride for adult women was 2.08E-17, followed by 2.00E-17 for adult men, and 2.73E-17 for children. The LCR of chloroform for adult women was 5.99E-16, 5.76E-16 for adult men, and 7.86E-16 for children. The LCR for dichloromethane for adult women was 1.24E-16, 1.19E-16 for adult men, and 1.63E-16 for children.

Table 4.2: Life time cancer risk (LCR) for carcinogenic risk of non-methane organic compound

Non-methane organic compound	Life time cancer risk (LCR)		
	Adult women	Adult men	Child
Acrylonitrile	3.74E-13	3.59E-13	4.90E-13
Carbon tetrachloride	2.08E-17	2.00E-17	2.73E-17
Chloroform	5.99E-16	5.76E-16	7.86E-16
Dichloromethane	1.24E-16	1.19E-16	1.63E-16

Table 4.3 shows the hazard quotient (HQ) for non-carcinogenic risk compound such as acrylonitrile, carbon disulphide, carbon tetrachloride, chloroethane, dichloromethane, ethylbenzene, and hydrogen sulphide. The HQ for each compound was within an acceptable range.The HQ of acrylonitrile for adult women, adult men and child were 2.83E-09, 2.91E-09, 1.44E-08. The HQ of carbon disulfide for adult women, adult men and child were 9.08E-08, 9.32E-08, 4.62E-07. The HQ of carbon tetrachloride for adult women, adult men and child were 8.95E-11, 9.18E-11, 4.56E-10. The HQ of chloroethane for adult women, adult men, and child were 2.80E-06, 2.87E-06, 1.42E-05. The HQ of dichloromethane for adult women, adult men, and child were 1.92E-06, 1.97E-06, 9.77E-06. The HQ of ethylbenzene for adult women, adult men and child were 1.03E-05, 1.06E-05, 5.25E-05. The HQ of hydrogen sulphide for adult women, adult men and child were 1.59E-08, 1.63E-08, 8.09E-08 respectively.

Table 4.3: Hazard quotient (HQ) for non-carcinogenic risk

Non-methane organic compound	Hazard quotient(HQ)		
	Adult women	Adult men	Child
Acrylonitrile	2.83E-09	2.91E-09	1.44E-08
Carbon disulfide	9.08E-08	9.32E-08	4.62E-07
Carbon tetrachloride	8.95E-11	9.18E-11	4.56E-10
Chloroethane	2.80E-06	2.87E-06	1.42E-05

Dichloromethane	1.92E-06	1.97E-06	9.77E-06
Ethylbenzene	1.03E-05	1.06E-05	5.25E-05
Hydrogen sulfide	1.59E-08	1.63E-08	8.09E-08

4.3 Greenhouse gases avoidance (CH_4, CO_2), environmental pollution and health risk reduction of polluter pays principle (PPP) implementation scenario's in the study area.

Table 4.4 highlights the emission of greenhouse gases (CH_4, CO_2), environmental pollution of PPP implementation scenario's in the study area. There were four different waste disposal methods for each scenario 1, scenario 2 and scenario 3. The highest emission of greenhouse gases was 6058.96 tonnes for methane and 151,473.88 tonnes for carbon dioxide equivalent in scenario 1 landfill. Scenario 1 landfill has shown the highest leachate production compared to other scenarios which is 29,340.24 m^3. The heavy metal contain in leachate was higher in landfill of scenario 1 compared to other landfill in scenario 2 and scenario 3. The emission of non-methane organic compound was higher in landfill scenario 1 compared to other scenarios.

The reduction of greenhouse gases (CH_4, CO_2) was higher in scenario 3 recycle compared to scenario 1 and scenario 2 recycle. The leachate reduction in scenario 3 recycle was -10,478.32 m^3 and it was the highest reduction compared to scenario 1 and scenario 2 recycle. The reduction of cadmium, chromium, copper, lead and zinc in leachate was -2.10E-02 m^3, -6.29E-02 m^3, -5.24E-02 m^3, -1.57E-01 m^3, -1.57E-01 m^3. The recycle in scenario 3 was the highest reduction of heavy metal compared to scenario 1 recycle and scenario 2 recycle. The reduction of non-methane organic compound was higher in scenario 3 recycle compared to scenario 1 recycle and scenario 2 recycle.

Scenario 3 incineration shows the highest reduction of methane gases and carbon dioxide equivalent compared to other scenarios. The reduction of methane gases and carbon dioxide equivalent was -1298.35 tonnes and -36,353.73 tonnes respectively. The leachate reduction in scenario 3 incineration was the highest compared to other scenarios. The reduction of cadmium, chromium, copper, lead, zinc, and iron in leachate was highest in incineration scenario 3 which is -1.26E-02 m^3, -3.77E-02 m^3, -3.14E-02 m^3, -9.43E-02 m^3, -9.43E-02m^3. The reduction of non-methane organic compound was higher in scenario 3 incineration compared to scenario 1 and scenario 2, incineration.

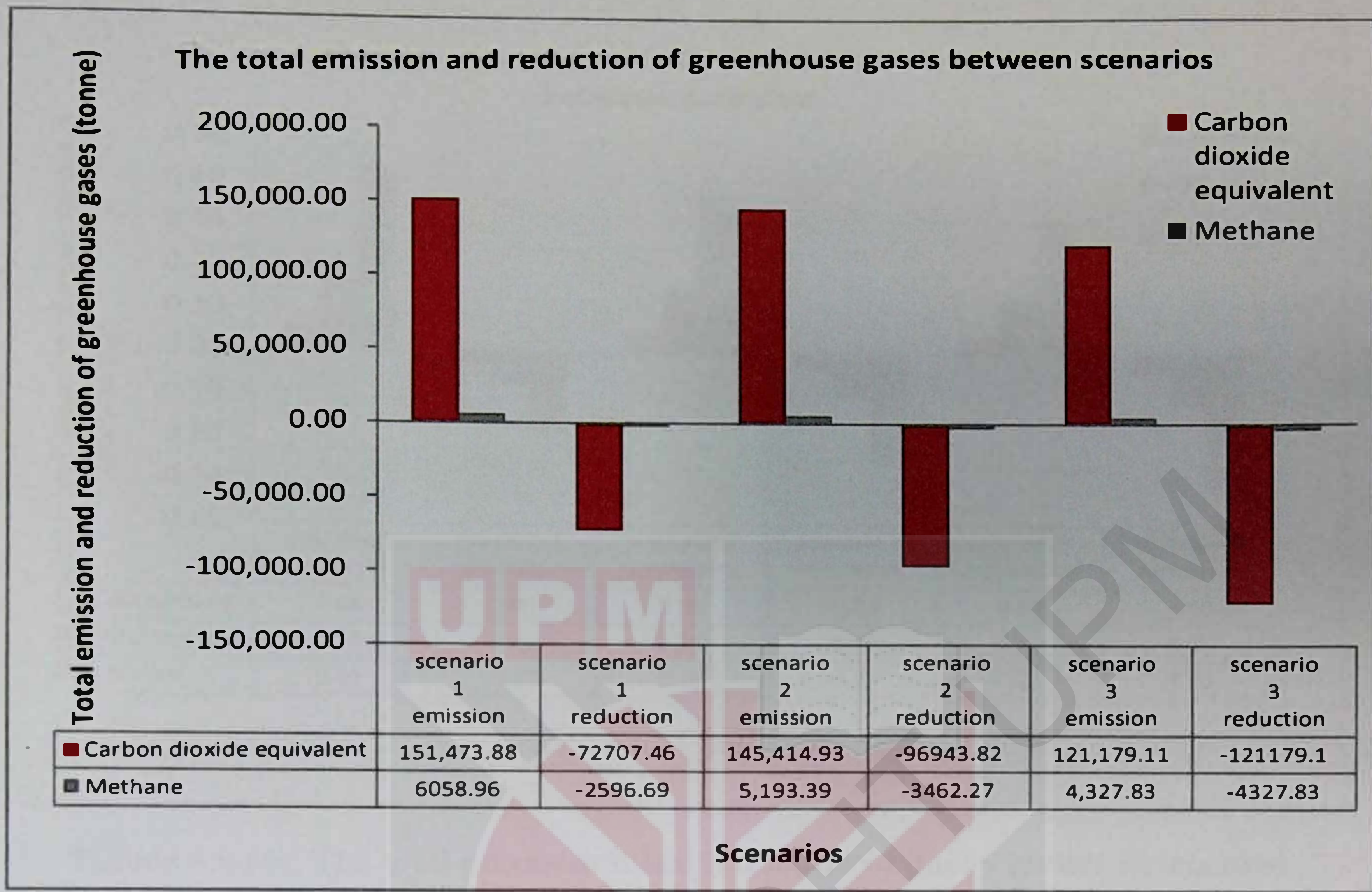
The reduction of greenhouse gases (CH_4, CO_2) was higher in scenario 2 composting and scenario 3 composting compared to scenario 1 composting. The reduction of methane gases and carbon dioxide equivalent in scenario 2 and scenario 3 composting was -865.57 tonnes and -24,325.82 tonnes respectively. The leachate reduction was -4191.46 m^3 in scenario 2 and scenario 3 composting. It is the highest reduction of leachate compared to other scenario. The reduction of heavy metals level in leachate was highest in scenario 2 and scenario 3 composting compared to scenario 1 composting. The reduction of non-methane organic compound (NMOC) was highest in scenario 2 and scenario 3 composting.

Table 4.4 The emission and avoidance of greenhouse gases (CH_4, CO_2) and environmental pollution of polluter pays principle (PPP) implementation scenario's in the study area.

	Scenario 1				Scenario 2				Scenario 3			
	Landfill (70%)	Recycle (20%)	Incineration (5%)	Composting (5%)	Landfill (60%	Recycle (20%)	Incineration (10%)	Composting (10%)	Landfill (50%)	Recycle (25%)	Incineration (15%)	Composting (10%)
Volume of waste (tonnes/year)	139,715.43	-39,918.70	-9,979.67	-9,979.67	119,756.09	-39,918.70	-19,959.35	-19,959.35	99,796.74	-49,898.37	-29,939.02	-19,959.35
GHG gases												
Methane (t)	6058.96	-1731.13	-432.78	-432.78	5,193.39	-1,731.13	-865.57	-865.57	4,327.83	-2,163.91	-1,298.35	-865.57
Carbon dioxide equivalent (t)	151,473.88	-48,471.64	-12,117.91	-12,117.91	145,414.93	-48,471.64	-24,235.82	-24,235.82	121,179.11	-60,589.55	-36,353.73	-24,235.82
Leachate (m^3)	29,340.24	-8,382.93	-2,095.73	-2,095.73	25,148.78	-8,382.93	-4,191.46	-4,191.46	20,957.32	-10,478.66	-6,287.19	-4,191.46
Heavy metals(kg)												
cadmium(Cd)	5.87E-02	-1.68E-02	-4.19E-03	-4.19E-03	5.03E-02	-1.68E-02	-8.38E-03	-8.38E-03	4.19E-02	-2.10E-02	-1.26E-02	-8.38E-03
chromium(Cr)	1.76E-01	-5.03E-02	-1.26E-02	-1.26E-02	1.51E-01	-5.03E-02	-2.51E-02	-2.51E-02	1.26E-01	-6.29E-02	-3.77E-02	-2.51E-02
copper (Cu)	1.47E-01	-4.19E-02	-1.05E-02	-1.05E-02	1.26E-01	-4.19E-02	-2.10E-02	-2.10E-02	1.05E-01	-5.24E-02	-3.14E-02	-2.10E-02
Lead (Pb)	4.40E-01	-1.26E-01	-3.14E-02	-3.14E-02	3.77E-01	-1.26E-01	-6.29E-02	-6.29E-02	3.14E-01	-1.57E-01	-9.43E-02	-6.29E-02
Zinc (Zn)	4.40E-01	-1.26E-01	-3.14E-02	-3.14E-02	3.77E-01	-1.26E-01	-6.29E-02	-6.29E-02	3.14E-01	-1.57E-01	-9.43E-02	-6.29E-02

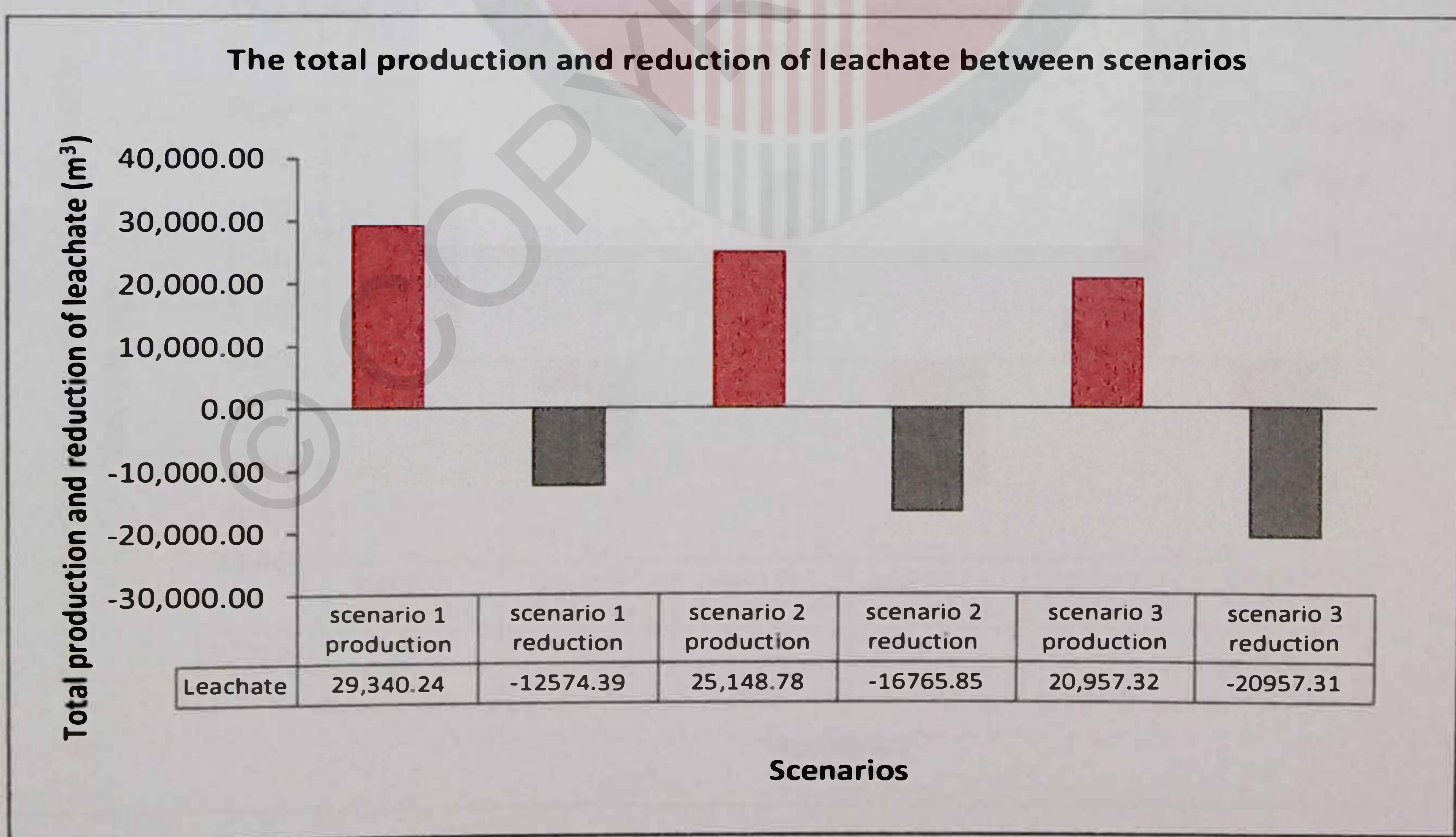
NMOC (m^3)											
Acrylonitrile	2.93E-02	-8.38E-03	-2.09E-03	-2.09E-03	2.51E-02	-8.38E-03	-4.19E-03	-4.19E-03	2.09E-02	-1.05E-02	-6.28E-03	-4.19E-03
Carbon disulphide	2.69E-03	-7.67E-04	-1.92E-04	-1.92E-04	2.30E-03	-7.67E-04	-3.84E-04	-3.84E-04	1.92E-03	-9.59E-04	-5.76E-04	-3.84E-04
Carbon tetrachloride	1.85E-05	-5.29E-06	-1.32E-06	-1.32E-06	1.59E-05	-5.29E-06	-2.65E-06	-2.65E-06	1.32E-05	-6.62E-06	-3.97E-06	-2.65E-06
Carbonyl sulphide	2.27E-03	-6.48E-04	-1.62E-04	-1.62E-04	1.95E-03	-6.48E-04	-3.24E-04	-3.24E-04	1.62E-03	-8.11E-04	-4.86E-04	-3.24E-04
Chlorobenzene	1.16E-03	-3.31E-04	-8.27E-05	-8.27E-05	9.92E-04	-3.31E-04	-1.65E-04	-1.65E-04	8.27E-04	-4.14E-04	-2.48E-04	-1.65E-04
Chloroethane	5.79E-03	-1.65E-03	-4.14E-04	-4.14E-04	4.96E-03	-1.65E-03	-8.27E-04	-8.27E-04	4.14E-03	-2.07E-03	-1.24E-03	-8.27E-04
Chloroform	1.39E-04	-3.97E-05	-9.92E-06	-9.92E-06	1.19E-04	-3.97E-05	-1.98E-05	-1.98E-05	9.92E-05	-4.96E-05	-2.98E-05	-1.98E-05
Dichloromethane	6.62E-02	-1.89E-02	-4.73E-03	-4.73E-03	5.68E-02	-1.89E-02	-9.46E-03	-9.46E-03	4.73E-02	-2.37E-02	-1.42E-02	-9.46E-03
Ethylbenzene	2.14E-02	-6.10E-03	-1.53E-03	-1.53E-03	1.83E-02	-6.10E-03	-3.05E-03	-3.05E-03	1.53E-02	-7.63E-03	-4.58E-03	-3.05E-03
Hydrogen sulphide (H^2S)	1.64E-01	-4.70E-02	-1.17E-02	-1.17E-02	1.41E-01	-4.70E-02	-2.35E-02	-2.35E-02	1.17E-01	-5.87E-02	-3.52E-02	-2.35E-02

The -ve sign indicate the reduction emission of PPP implementation scenario



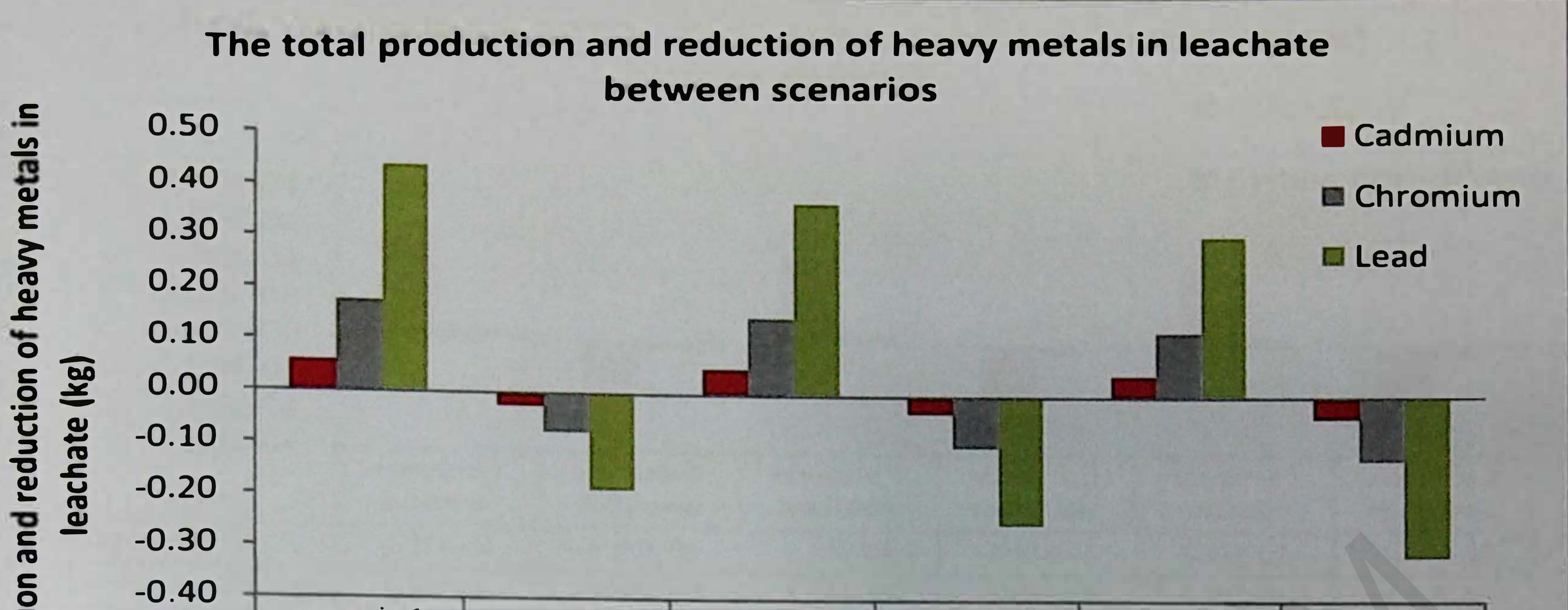
	scenario 1 emission	scenario 1 reduction	scenario 2 emission	scenario 2 reduction	scenario 3 emission	scenario 3 reduction
Carbon dioxide equivalent	151,473.88	-72707.46	145,414.93	-96943.82	121,179.11	-121179.1
Methane	6058.96	-2596.69	5,193.39	-3462.27	4,327.83	-4327.83

Figure 4.7: The total emission and reduction of greenhouse gases between scenarios



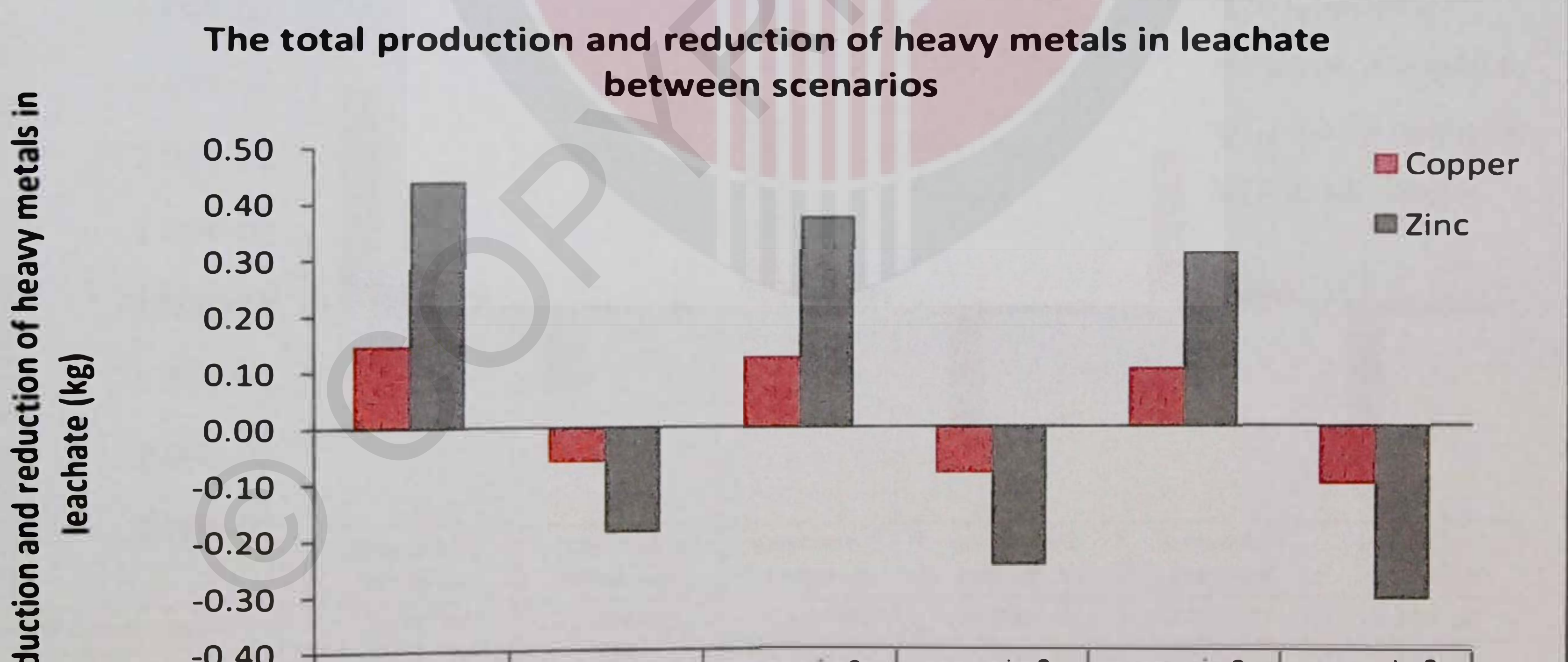
	scenario 1 production	scenario 1 reduction	scenario 2 production	scenario 2 reduction	scenario 3 production	scenario 3 reduction
Leachate	29,340.24	-12574.39	25,148.78	-16765.85	20,957.32	-20957.31

Figure 4.8: The total production and reduction of leachate between scenarios



	scenario 1 production	scenario 1 reduction	scenario 2 production	scenario 2 reduction	scenario 3 production	scenario 3 reduction
Cadmium	0.06	-0.03	0.05	-0.03	0.04	-0.04
Chromium	0.18	-0.08	0.15	-0.10	0.13	-0.13
Lead	0.44	-0.19	0.38	-0.25	0.31	-0.31

Figure 4.9 (a): The total production and reduction of heavy metals in leachate between scenarios



	scenario 1 production	scenario 1 reduction	scenario 2 production	scenario 2 reduction	scenario 3 production	scenario 3 reduction
Copper	0.15	-0.06	0.13	-0.08	0.11	-0.11
Zinc	0.44	-0.19	0.38	-0.25	0.31	-0.31

Figure 4.9 (b): The total production and reduction of heavy metals in leachate between scenarios

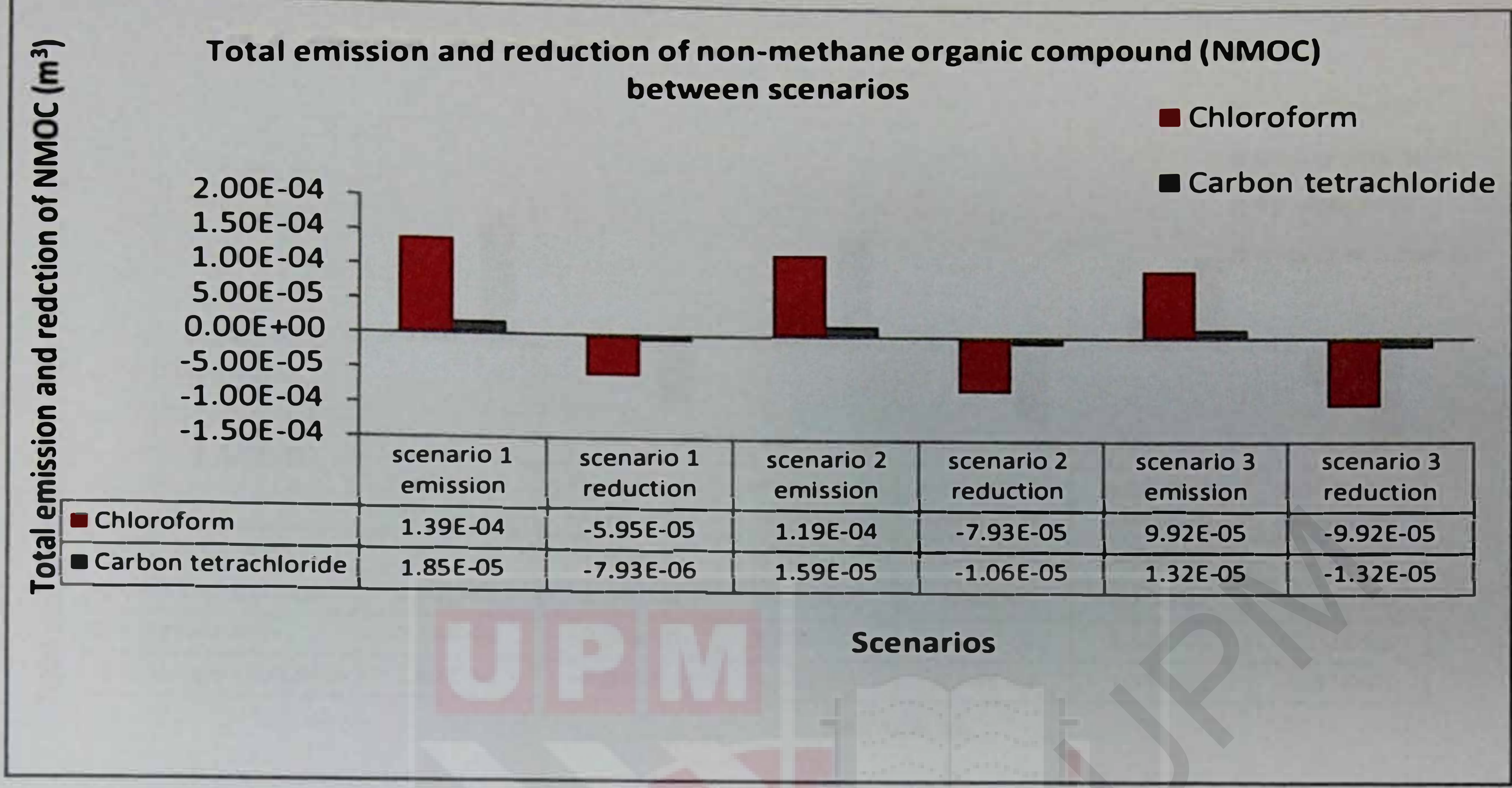


Figure 4.10 (a): Total emission and reduction of non-methane organic compound (NMOC) between scenarios

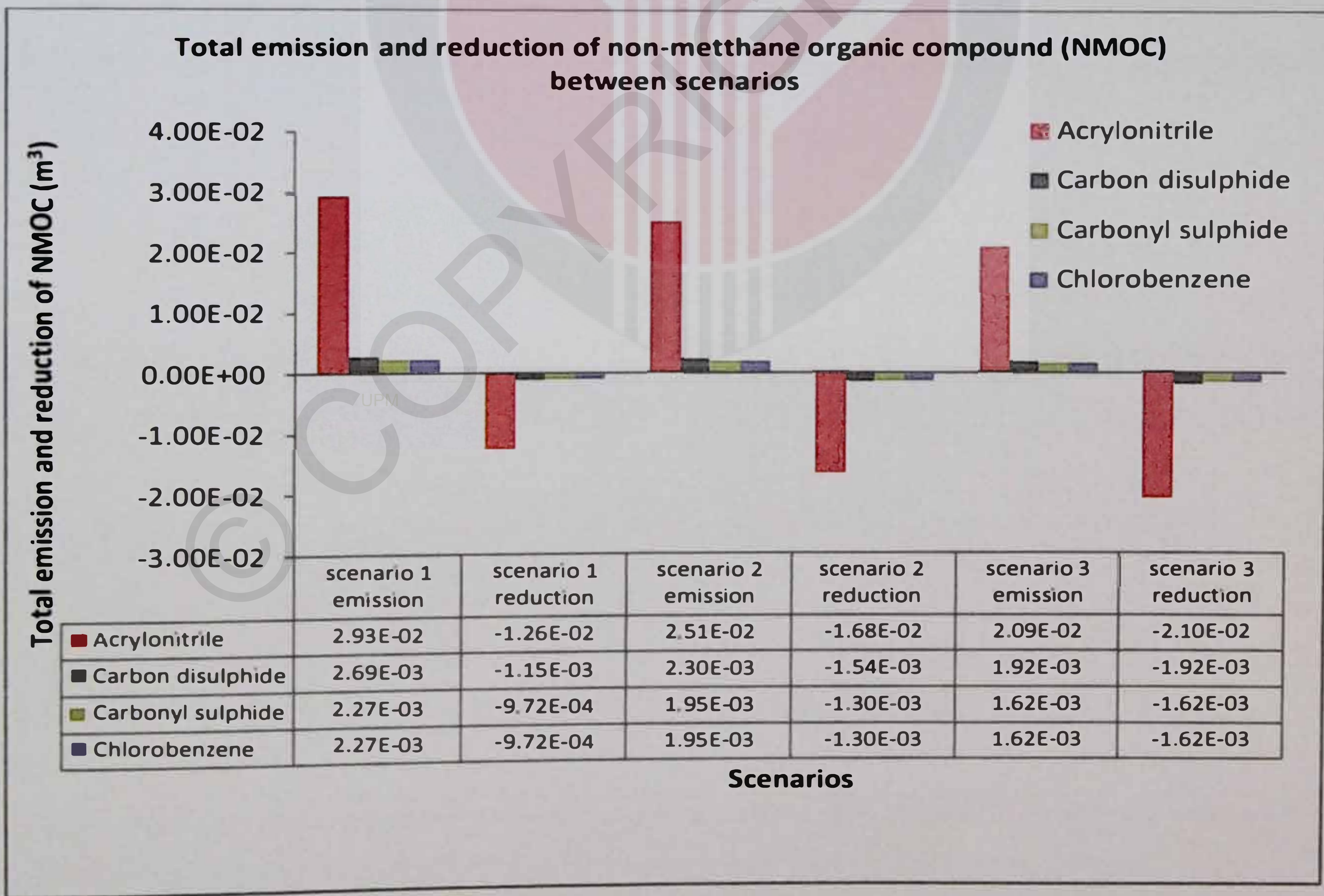
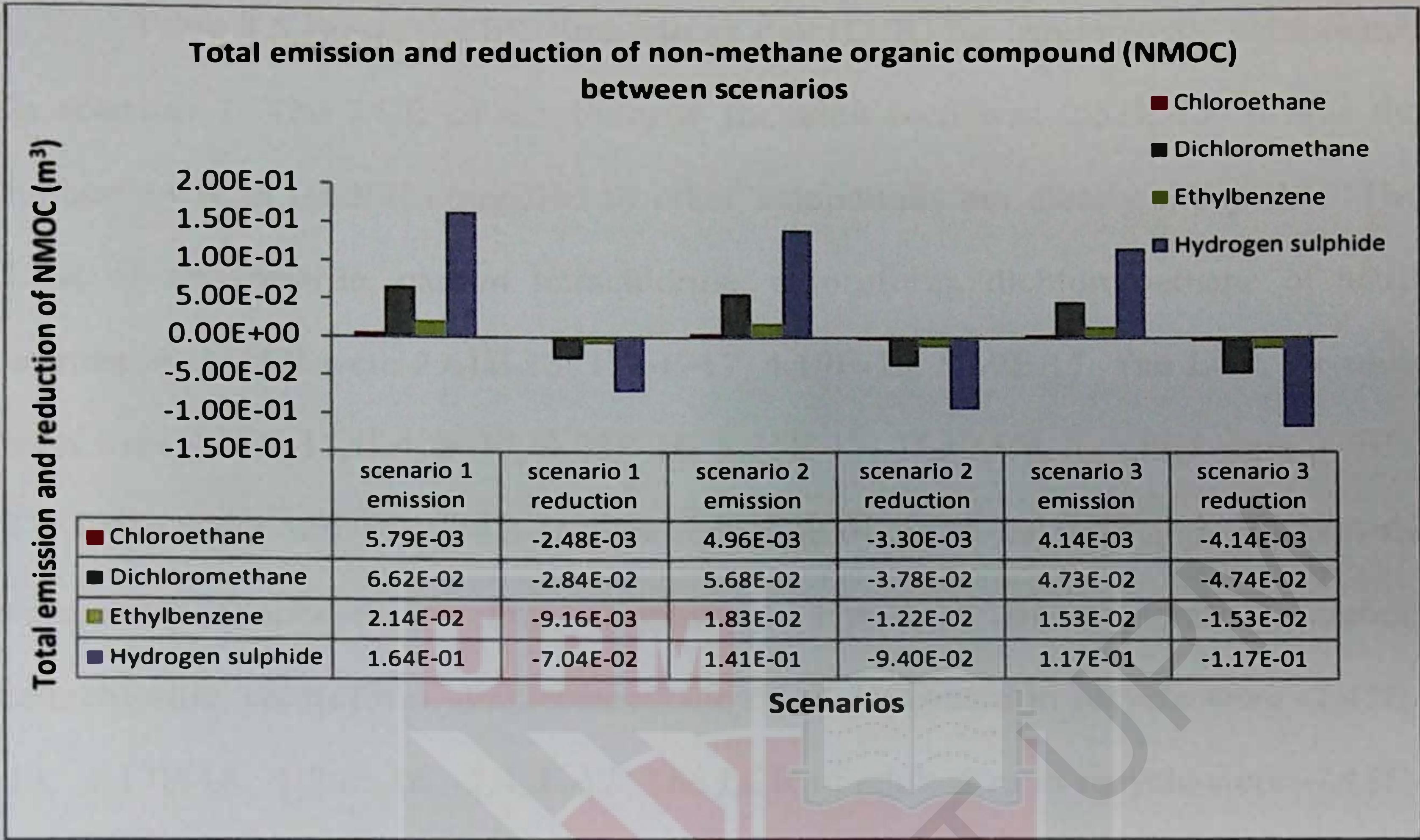


Figure 4.10 (b): Total emission and reduction of non-methane organic compound (NMOC) between scenarios



	scenario 1 emission	scenario 1 reduction	scenario 2 emission	scenario 2 reduction	scenario 3 emission	scenario 3 reduction
Chloroethane	5.79E-03	-2.48E-03	4.96E-03	-3.30E-03	4.14E-03	-4.14E-03
Dichloromethane	6.62E-02	-2.84E-02	5.68E-02	-3.78E-02	4.73E-02	-4.74E-02
Ethylbenzene	2.14E-02	-9.16E-03	1.83E-02	-1.22E-02	1.53E-02	-1.53E-02
Hydrogen sulphide	1.64E-01	-7.04E-02	1.41E-01	-9.40E-02	1.17E-01	-1.17E-01

Figure 4.10 (c): Total emission and reduction of non-methane organic compound (NMOC) between scenarios

Table 4.5 shows the life time cancer risk (LCR) for carcinogenic compounds in scenario 1. The LCR of acrylonitrile for adult men was 2.51E-13. It was the highest LCR in landfill compared to other compounds but clearly acceptable. The LCR of acrylonitrile, carbon tetrachloride, chloroform, dichloromethane of adult women in landfill were 2.61E-13, 1.46E-17, 4.19E-16, 8.69E-17. The LCR for adult men were 2.51E-13, 1.40E-17, 4.03E-16, 8.35E-17. The LCR for child were 3.43E-13, 1.91E-17, 5.50E-16, 1.14E-16. The reduction of health risk was higher in recycle compared to incineration and composting. The LCR of acrylonitrile, carbon tetrachloride, chloroform, dichloromethane of adult women in recycle were -7.47E-14, -4.17E-18, -1.20E-16, -2.48E-17. The LCR of adult men in recycle were -7.18E-14, -4.01E-18, -1.15E-16, and -2.39E-17. The LCR of child were -9.81E-14, -5.47E-18, -1.57E-16, and -3.26E-17. The LCR of acrylonitrile, carbon tetrachloride, chloroform, dichloromethane of adult women in incineration were -1.87E-14, -1.04E-18, -2.99E-17, and -6.20E-18. The LCR for adult men were -1.80E-14, -1.00E-18, -2.88E-17, -5.97E-18. The LCR for child were -2.45E-14, -1.37E-18, -3.93E-17-3.93E-17, -8.14E-18. The LCR of acrylonitrile,carbon tetrachloride, chloroform, dichloromethane for adult women in composting were -1.87E-14, -1.04E-18, -2.99E-17 and -6.20E-18. The LCR for adult men were -1.80E-14, -1.00E-18, -2.88E-17, -5.97E-18. The LCR for child were -2.45E-14, -1.37E-18, -3.93E-17, -8.14E-18.

Table 4.5: Life time cancer risk (LCR) for carcinogenic risk compound of scenario 1

Compound	Life time cancer risk (LCR) Scenario 1											
	Landfill			Recycle			Incineration			Composting		
	Adult women	Adult men	Child	Adult women	Adult men	Child	Adult women	Adult men	Child	Adult women	Adult men	Child
Acrylonitrile	2.61E-13	2.51E-13	3.43E-13	-7.47E-14	-7.18E-14	-9.81E-14	-1.87E-14	-1.80E-14	-2.45E-14	-1.87E-14	-1.80E-14	-2.45E-14
Carbon tetrachloride	1.46E-17	1.40E-17	1.91E-17	-4.17E-18	-4.01E-18	-5.47E-18	-1.04E-18	-1.00E-18	-1.37E-18	-1.04E-18	-1.00E-18	-1.37E-18
Chloroform	4.19E-16	4.03E-16	5.50E-16	-1.20E-16	-1.15E-16	-1.57E-16	-2.99E-17	-2.88E-17	-3.93E-17	-2.99E-17	-2.88E-17	-3.93E-17
Dichloromethane	8.69E-17	8.35E-17	1.14E-16	-2.48E-17	-2.39E-17	-3.26E-17	-6.20E-18	-5.97E-18	-8.14E-18	-6.20E-18	-5.97E-18	-8.14E-18

The -ve sign indicate the reduction of health risk of PPP implementation scenario

Table 4.6 shows the life time cancer (LCR) for carcinogenic risk compound in scenario 2. The LCR of acrylonitrile for adult men was 2.16E-13. It was the highest LCR in landfill compared to other compounds but clearly acceptable. The LCR of acrylonitrile, carbon tetrachloride, chloroform, dichloromethane of adult women in landfill were 2.24E-13, .25E-17, 3.59E-16, 7.45E-17. The LCR for adult men were 2.16E-13, 1.20E-17, 3.45E-16, 7.16E-17. The LCR for child were 2.94E-13, 1.64E-17, 4.72E-16, 9.77E-17. The reduction of health risk was higher in recycle compared to incineration and composting. The LCR of acrylonitrile, carbon tetrachloride, chloroform, dichloromethane of adult women in recycle were -7.47E-14, -4.17E-18, -1.20E-16, -2.48E-17. The LCR for adult men were -7.18E-14, -4.01E-18, -1.15E-16, -2.39E-17. The LCR for child were -9.81E-14, -5.47E-18, -5.47E-18, -3.26E-17. The LCR of acrylonitrile, carbon tetrachloride, chloroform, dichloromethane of adult women in incineration were -3.74E-14, -2.08E-18, -5.99E-17, -1.24E-17. The LCR for adult men were -3.59E-14, -2.00E-18, -5.76E-17, -1.19E-17. The LCR for child were -4.90E-14, -2.73E-18, -7.86E-17, -1.63E-17. The LCR of acrylonitrile, carbon tetrachloride, chloroform, dichloromethane of adult women in composting were -3.74E-14, -2.08E-18, -5.99E-17, -1.24E-17. The LCR for adult men were -3.59E-14, -2.00E-18, -5.76E-17, -1.19E-17. The LCR for child were-4.90E-14,-2.73E-18,-7.86E-17,-1.63E-17.

Table 4.6: Life time cancer risk (LCR) for carcinogenic risk compound of scenario 2

Compound	Life time cancer risk (LCR) Scenario 2											
	Landfill			Recycle			Incineration			Composting		
	Adult women	Adult men	Child	Adult women	Adult men	Child	Adult women	Adult men	Child	Adult women	Adult men	Child
Acrylonitrile	2.24E-13	2.16E-13	2.94E-13	-7.47E-14	-7.18E-14	-9.81E-14	-3.74E-14	-3.59E-14	-4.90E-14	-3.74E-14	-3.59E-14	-4.90E-14
Carbon tetrachloride	1.25E-17	1.20E-17	1.64E-17	-4.17E-18	-4.01E-18	-5.47E-18	-2.08E-18	-2.00E-18	-2.73E-18	-2.08E-18	-2.00E-18	-2.73E-18
Chloroform	3.59E-16	3.45E-16	4.72E-16	-1.20E-16	-1.15E-16	-1.57E-16	-5.99E-17	-5.76E-17	-7.86E-17	-5.99E-17	-5.76E-17	-7.86E-17
Dichloromethane	7.45E-17	7.16E-17	9.77E-17	-2.48E-17	-2.39E-17	-3.26E-17	-1.24E-17	-1.19E-17	-1.63E-17	-1.24E-17	-1.19E-17	-1.63E-17

The –ve sign indicate the reduction of health risk of PPP implementation scenario

Table 4.7 shows the life time cancer (LCR) for carcinogenic risk compound in scenario 3. The LCR of acrylonitrile for adult men was 1.80E-13. It was the highest LCR in landfill compared to other compounds but clearly acceptable. The LCR of acrylonitrile, carbon tetrachloride, chloroform, dichloromethane of adult women in landfill were 1.87E-13, 1.04E-17, 2.99E-16, 6.20E-17. The LCR for adult men were 1.80E-13, 1.00E-17, 2.88E-16, 5.97E-17. The LCR for child were 2.45E-13, 1.37E-17, 3.93E-16, 8.14E-17. The reduction of health risk was higher in recycle compared to incineration and composting. The LCR of acrylonitrile, carbon tetrachloride, chloroform, dichloromethane of adult women for recycle were -9.34E-14, -5.21E-18, -1.50E-16, -3.10E-17. The LCR for adult men were -8.98E-14, -5.01E-18, -1.44E-16, -2.98E-17. The LCR for child were -1.23E-13, -6.83E-18, -1.97E-16, -4.07E-17.. The LCR of acrylonitrile, carbon tetrachloride, chloroform, dichloromethane of adult women for incineration were -5.60E-14, -3.12E-18, -8.98E-17, -1.86E-17. The LCR for adult men were -5.39E-14, -3.00E-18, -8.64E-17, -1.79E-17. The LCR for child were -7.35E-14, -4.10E-18, -1.18E-16, -2.44E-17. The LCR of acrylonitrile, carbon tetrachloride, chloroform, dichloromethane of adult women for composting were -3.74E-14, -2.08E-18, -5.99E-17, -1.24E-17. The LCR for adult men were -3.59E-14, -2.00E-18, -5.76E-17, -1.19E-17. The LCR for child were-4.90E-14,-2.73E-18,-7.86E-17,-1.63E-17.

Table 4.7: Life time cancer risk (LCR) for carcinogenic risk compound of scenario 3

Compound	Life time cancer risk (LCR) Scenario 3											
	Landfill			Recycle			Incineration			Composting		
	Adult women	Adult men	Child	Adult women	Adult men	Child	Adult women	Adult men	Child	Adult women	Adult men	Child
Acrylonitrile	1.87E-13	1.80E-13	2.45E-13	-9.34E-14	-8.98E-14	-1.23E-13	-5.60E-14	-5.39E-14	-7.35E-14	-3.74E-14	-3.59E-14	-4.90E-14
Carbon tetrachloride	1.04E-17	1.00E-17	1.37E-17	-5.21E-18	-5.01E-18	-6.83E-18	-3.12E-18	-3.00E-18	-4.10E-18	-2.08E-18	-2.00E-18	-2.73E-18
Chloroform	2.99E-16	2.88E-16	3.93E-16	-1.50E-16	-1.44E-16	-1.97E-16	-8.98E-17	-8.64E-17	-1.18E-16	-5.99E-17	-5.76E-17	-7.86E-17
Dichloromethane	6.20E-17	5.97E-17	8.14E-17	-3.10E-17	-2.98E-17	-4.07E-17	-1.86E-17	-1.79E-17	-2.44E-17	-1.24E-17	-1.19E-17	-1.63E-17

The –ve sign indicate the reduction of health risk of PPP implementation scenario

Table 4.8 shows the hazard quotient (HQ) for non-carcinogenic compound in scenario 1. The HQ of ethylbenze for child was 3.68E-05. It was the highest HQ in landfill compared to other compound.

Table 4.8: Hazard Quotient (HQ) for non-carcinogenic risk compound of scenario 1

Compound	Hazard Quotient (HQ) Scenario 1											
	Landfill			Recycle			Incineration			Composting		
	Adult women	Adult men	Child	Adult women	Adult men	Child	Adult women	Adult men	Child	Adult women	Adult men	Child
Acrylonitrile	1.98E-09	2.03E-09	1.01E-08	-5.66E-10	-5.81E-10	-2.88E-09	-1.42E-10	-1.45E-10	-7.21E-10	-1.42E-10	-1.45E-10	-7.21E-10
Carbon disulfide	6.36E-08	6.52E-08	3.24E-07	-1.82E-08	-1.86E-08	-9.25E-08	-4.54E-09	-4.66E-09	-2.31E-08	-4.54E-09	-4.66E-09	-2.31E-08
Carbon tetrachloride	6.26E-11	6.43E-11	3.19E-10	-1.79E-11	-1.84E-11	-9.11E-11	-4.47E-12	-4.59E-12	-2.28E-11	-4.47E-12	-4.59E-12	-2.28E-11
Chloroethane	1.96E-06	2.01E-06	9.97E-06	-5.59E-07	-5.74E-07	-2.85E-06	-1.40E-07	-1.43E-07	-7.12E-07	-1.40E-07	-1.43E-07	-7.12E-07
Dichloromethane	1.34E-06	1.38E-06	6.84E-06	-3.84E-07	-3.94E-07	-1.95E-06	-9.60E-08	-9.85E-08	-4.89E-07	-9.60E-08	-9.85E-08	-4.89E-07
Ethylbenzene	7.22E-06	7.41E-06	3.68E-05	-2.06E-06	-2.12E-06	-1.05E-05	-5.16E-07	-5.29E-07	-2.63E-06	-5.16E-07	-5.29E-07	-2.63E-06
Hydrogen sulfide	1.11E-08	1.14E-08	5.66E-08	-3.18E-09	-3.26E-09	-1.62E-08	-7.94E-10	-8.15E-10	-4.04E-09	-7.94E-10	-8.15E-10	-4.04E-09

The –ve sign indicate the reduction of health risk of PPP implementation scenario

Table 4.9 shows the hazard quotient (HQ) for non-carcinogenic compound in scenario 2. The HQ of ethylbenze for child was 3.15E-05. It was the highest HQ in landfill compared to others compound.

Table 4.9: Hazard Quotient (HQ) for non-carcinogenic risk compound of scenario 2

Compound	Hazard Quotient (HQ) Scenario 2											
	Landfill			Recycle			Incineration			Composting		
	Adult women	Adult men	Child	Adult women	Adult men	Child	Adult women	Adult men	Child	Adult women	Adult men	Child
Acrylonitrile	1.70E-09	1.74E-09	8.65E-09	-5.66E-10	-5.81E-10	-2.88E-09	-2.83E-10	-2.91E-10	-1.44E-09	-2.83E-10	-2.91E-10	-1.44E-09
Carbon disulfide	5.45E-08	5.59E-08	2.77E-07	-1.82E-08	-1.86E-08	-9.25E-08	-9.08E-09	-9.32E-09	-4.62E-08	-9.08E-09	-9.32E-09	-4.62E-08
Carbon tetrachloride	5.37E-11	5.51E-11	2.73E-10	-1.79E-11	-1.84E-11	-9.11E-11	-8.95E-12	-9.18E-12	-4.56E-11	-8.95E-12	-9.18E-12	-4.56E-11
Chloroethane	1.68E-06	1.72E-06	8.54E-06	-5.59E-07	-5.74E-07	-2.85E-06	-2.80E-07	-2.87E-07	-1.42E-06	-2.80E-07	-2.87E-07	-1.42E-06
Dichloromethane	1.15E-06	1.18E-06	5.86E-06	-3.84E-07	-3.94E-07	-1.95E-06	-1.92E-07	-1.97E-07	-9.77E-07	-1.92E-07	-1.97E-07	-9.77E-07
Ethylbenzene	6.19E-06	6.35E-06	3.15E-05	-2.06E-06	-2.12E-06	-1.05E-05	-1.03E-06	-1.06E-06	-5.25E-06	-1.03E-06	-1.06E-06	-5.25E-06
Hydrogen sulfide	9.53E-09	9.78E-09	4.85E-08	-3.18E-09	-3.26E-09	-1.62E-08	-1.59E-09	-1.63E-09	-8.09E-09	-1.59E-09	-1.63E-09	-8.09E-09

The –ve sign indicate the reduction of health risk of PPP implementation scenario

Table 4.10 shows the hazard quotient (HQ) for non-carcinogenic compound in scenario 3. The HQ of ethylbenze for child was 2.63E-05. It was the highest HQ in landfill compared to others compound.

Table 4.10: Hazard Quotient (HQ) for non-carcinogenic risk compound of scenario 3

Compound	Hazard quotient (HQ) Scenario 3											
	Landfill			Recycle			Incineration			Composting		
	Adult women	Adult men	Child	Adult women	Adult men	Child	Adult women	Adult men	Child	Adult women	Adult men	Child
Acrylonitrile	1.42E-09	1.45E-09	7.21E-09	-7.08E-10	-7.27E-10	-3.61E-09	-4.25E-10	-4.36E-10	-2.16E-09	-2.83E-10	-2.91E-10	-1.44E-09
Carbon disulfide	4.54E-08	4.66E-08	2.31E-07	-2.27E-08	-2.33E-08	-1.16E-07	-1.36E-08	-1.40E-08	-6.94E-08	-9.08E-09	-9.32E-09	-4.62E-08
Carbon tetrachloride	4.47E-11	4.59E-11	2.28E-10	-2.24E-11	-2.30E-11	-1.14E-10	-1.34E-11	-1.38E-11	-6.83E-11	-8.95E-12	-9.18E-12	-4.56E-11
Chloroethane	1.40E-06	1.43E-06	7.12E-06	-6.99E-07	-7.17E-07	-3.56E-06	-4.19E-07	-4.30E-07	-2.14E-06	-2.80E-07	-2.87E-07	-1.42E-06
Dichloromethane	9.60E-07	9.85E-07	4.89E-06	-4.80E-07	-4.92E-07	-2.44E-06	-2.88E-07	-2.95E-07	-1.47E-06	-1.92E-07	-1.97E-07	-9.77E-07
Ethylbenzene	5.16E-06	5.29E-06	2.63E-05	-2.58E-06	-2.65E-06	-1.31E-05	-1.55E-06	-1.59E-06	-7.88E-06	-1.03E-06	-1.06E-06	-5.25E-06
Hydrogen sulfide	7.94E-09	8.15E-09	4.04E-08	-3.97E-09	-4.07E-09	-2.02E-08	-2.38E-09	-2.44E-09	-1.21E-08	-1.59E-09	-1.63E-09	-8.09E-09

The –ve sign indicate the reduction of health risk of PPP implementation scenario

CHAPTER 5

DISCUSSION

5.1 The characteristics (i.e. volume, waste composition) of solid waste disposed in landfill from 2011 to 2017 in Klang.

5.1.1 Volume of solid waste

The volume of municipal solid waste (MSW) has shown an increasing pattern from 2011 to 2017 in Jeram Sanitary landfill. The volume of MSW disposed has increased by 29.4% due to several factors such as rapid growing of populations, life style changes and rising community standards (Hassan et al., 2016). These factors lead to increasing in solid waste generation from household, institutional, commercial and industrial sector that will lead increasing of solid waste in landfill. Furthermore, Malaysia highly dependent on landfill as the main disposal method with 89% of the total solid waste ending up in the landfills (JPSPN, 2013). The population in Klang has been reported to produce more waste compare to other region in Malaysia with 1.35kg/capita/day (JPSPN, 2013). Furthermore, Act 672 is not implemented yet in Selangor. Act 672, subsection 74 (1) and (2), solid waste segregation at source is mandatory and fine will be posed to any person who fails to comply. Based on the national survey of waste generation, the recycling rate in Klang was 9.4% which is lower compared to other cities in Malaysia such as

Kuantan (18.4%), Kota Bahru (15.7%), and Sibu (15.6%) (JPSPN, 2013). This is one of the factors that lead in increasing of solid waste ending up in the landfilled.

Furthermore, low rate of recycling also one of the factors that contributes high volume of waste has been sent to the landfill for disposal. According to personal comment by SWCorp deputy chief executive officer (technical), he stated that the recycling rate in Malaysia was 17.5% in 2018. This scenario has proven that the participation among Malaysians is still low even though the awareness about the recycling is high. Based on the survey conducted by Solid Waste Management and Public Cleaning Corporation (PPSPPA, 2013), 99% of the 17,000 respondents were aware about recycling activity. However, only 68.8% of the respondents were committed in putting it to practice although there are many initiatives have been introduced. Furthermore, Hassan, Noordin & Sulaiman (2010) revealed that recycling activity was failed because the Malaysian population felt it was difficult to apply in their daily life. This can lead the disposal of waste to the landfill.

5.1.2 Waste composition

Food waste has shown the highest estimated waste composition and an increasing pattern from 2011 to 2017. Food waste is the major type of waste with fraction 44.3% (household) and 31.4% (institutional, commercial and industrial) respectively. The food waste production in Malaysia had reached 15,000 tonnes per day and almost 70% of the food waste ending up in the landfill (Ghafar, 2017). The food waste estimation from household is higher compare to institutional, commercial and industrial sector because of daily activity of the population in the area. The increasing number of Malaysian population contributes to the increase number of food waste due to economic development, population growth, and urbanization which is to fulfil the demand among the population. Lim et al., 2016 stated that the reasons of the issues become worse are because of the improvement or changes of eating habits according to the improvement of living standards, where nowadays everyone can afford more food products than a few years back and the rapid of human population and urbanisation.

5.2 Greenhouse gases emission (CH_4, CO_2), environmental pollution and health risk of the current waste landfilling practice in the study area.

5.2.1 Greenhouse gases emission (CH_4, CO_2)

The estimated emission of greenhouse gases (CH_4, CO_2-eq) has shown increasing pattern from 2011 to 2017. It is due to the increasing of waste that has been disposed in the landfill. The disposal of solid waste in the landfill were recognized as the major contributor of greenhouse gases emission (Tomonori et al., 2011). The deposited waste in the landfill that contain highly organic material (food, paper, wood, garden waste) will undergo decomposition process by microbes under anaerobic conditions and will produce methane, carbon dioxide and other gases compound (Afzanizam, 2016). Landfill generates greenhouse gases such as methane (50%), carbon dioxide (45%), and non-methane organic compound from the biodegradation process that can contribute to global warming (Ishigaki, 2011). Global warming can cause climate change that will affect the population by heavy precipitation, heat waves in susceptible area, drought, food, water and vector borne disease and malnutrition (Hoornweg & Perinaz, 2012).

The methane and carbon dioxide emission that were released from the decomposition process of municipal solid waste in the landfill can contribute to global warming. The high concentration of GHG can cause a reduction in outgoing infrared radiation, thus the earth's climate must change in order to restore the balance between incoming and outgoing radiation. The climatic change leads to global warming of the earth's surface and the lower atmosphere as warming up is the simplest way for the climate to release the energy. The global warming can increase the temperature of the earth. A small change in temperature rise can cause many other changes such as cloud cover and wind patterns (Latake, Pawar & Ranveer, 2015). Based on complex climate models, the "Intergovernmental Panel on Climate Change" in their third assessment report has forecast that global mean surface temperature will increase by 1.4°C to 5.8°C by the end of 2100.

The estimation of methane and carbon dioxide equivalent emission is higher in this study compared to previous study (Abushammala et al., 2015). It is due to different estimation method were used in both study. In this study, Tier 1 default method by the Inter-governmental Panel on Climate Change (IPCC) was used to estimate the emission of methane and carbon dioxide equivalent. The emission was based on the mass balance approach and used a number of empirical constant parameters (e.g., methane correction factor, degradable organic carbon). However, in the previous study, tier 2 and tier 3 default method were used based on First Order Decay (FOD) model to calculate the level of the emission. The IPCC and US

Environmental Protection Agency recommend the FOD model to be used to estimate the emission of methane because it provides a time dependent emission profile that reflects the pattern of waste degradation over time. So this will generate more accurate estimation of methane and carbon dioxide equivalent from the landfill (Abushammala, Ezlin, Basri, & Younes, 2015)

5.2.2 Leachate and heavy metals

The disposal of waste in the landfill cause production of leachate and heavy metal contain in the leachate. The estimated production of leachate and heavy metal contain were higher in the 2017 due to high volume of waste disposed in the landfill which is 231,605.63 tonne/year. The total estimated production of leachate in 2017 was 293,402.41 m^3. The disposal of waste in landfill will produce leachate due to percolation of rain water through waste dumps (Prabpai et al., 2009). Heavy metal is one of the most hazardous components in the leachate (Sumaiya et al.,2012). The disposal of the residual waste in the landfill will produce leachate containing heavy metals such as mercury, cadmium, copper, zinc, lead and iron (Vasanthi, Kaliappan, & Srinivasaraghavan, 2008). Heavy metal contaminations occur due to the subsequent migration of leachate from and within the landfill's waste cell (Agamuthu & Fauziah, 2010).

Agamuthu & Fauziah (2002) stated that the negative impacts of MSW landfill to the environment cause a wide range of concern such as increase the risk of explosion, odour problem, and contamination of leachate that contain heavy metals in soil and groundwater. Sumaiya et al (2014) in their study revealed that one of the most hazardous components in leachate is heavy metals. Furthermore, landfills especially in Asia contain high concentration of heavy metals in leachate from closed and active landfills (Emenike et al., 2011). This has become a great concern of leachate pollution in the water because it can resulting potential bioaccumulation of the pollutants (manganese, copper,zinc, iron, chromium, aluminium) in the aquatic organisms and humans (Fauziah, Emineke & Agamuthu, 2013) .

Morling (2010) stated that the heavy metal concentration is significantly higher in younger leachate where it is in acidic phase and can give threat to the environment. However, the estimation of heavy metals in the leachate in this study was observed to be of low concentrations compared to the previous study. This study suggests, it could be due to different of total waste that has been disposed to the landfill. Furthermore, the estimation of leachate production in the landfill did not exceed the acceptable conditions for discharge of leachate in Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill Regulations 2009). Zinc and lead has the highest production in leachate compared to cadmium, chromium, and copper. Jumaah, Othman, & Yusop, (2016) revealed that in their study the level of zinc in the leachate was high compared to other heavy metals such as cadmium, copper and barium but it does not exceed the standard discharge by American Public Health Association. The level of zinc is higher in the leachate is due to florescent tubes and batteries that have been disposed in the landfill (Chuangcham et al., 2008).

5.2.3 Non-methane organic compound and health risk

The emission of non-methane organic compound due to waste disposal of waste in the landfill can affect the human health. The highest emission of NMOC is hydrogen sulphide compared to other gases. However, hydrogen sulphide did not pose the health risk to the human population. It is because, landfill only emits a trace amount of NMOCs to the atmosphere during the decomposition process compared methane and carbon dioxide (Pazoki et al., 2015). The life time cancer risk (LCR) for carcinogenic risk compound (acrylonitrile, carbon tetrachloride, chloroform, and dichloromethane) was clearly acceptable. Furthermore, the hazard quotient (HQ) for non-carcinogenic risk compound (acrylonitrile, carbon disulphide, carbon tetrachloride, chloroethane, dichloromethane, ethylbenzene, and hydrogen sulphide) was clearly acceptable.

According to Chalvatzaki & Lazaridis (2010), the decomposition process of waste in the landfill usually produced less than 1% of non-methane organic compound (NMOC). NMOC are contained in the biogas in a small percentage that include various harmful and odour organic air pollutant. Despite their small concentration in the biogas emitted from the landfill, it can give risk to public health in the general population because of the harmful and toxic gases containing and unpleasant odour in regions adjacent to landfill

5.3 Greenhouse gases avoidance (CH_4, CO_2), environmental pollution and health risk reduction of polluter pays principle (PPP) implementation scenario's in the study area.

The application of polluter pays principle (PPP) has potential in reducing the environmental pollution and health risk for municipal solid waste by avoiding landfilling and initiating recycle, composting and incineration. The implementation of PAYT in the United States has led the diversion of perhaps 6.5 million tons of municipal solid waste (MSW) per year (4.6-8.3 million) that would otherwise have been landfilled (Skumatz & Freeman, 2006a). Furthermore, after implementation of unit pricing system, the recycling rate has increased steadily up to 59.8% in 2008 while landfill has decreased down to 20.3% in Korea(Korean Ministry of Environment, 2009) . It has shown that, polluter pays principle has the potential contribution on reduction of environmental pollution and health risk for municipal solid waste. Polluter Pay Principle (PPP) is a waste management scheme and pay as you throw (PAYT) is one of the approaches applied in this principle (Morlok et al., 2017). The aim of economic approach is to promote material recovery among waste producers (Morlok et., 2017). Some municipalities have adopted PAYT programs to educate the residents on the cost of waste disposal and promote the community efforts towards waste reduction (Di Leo & Salvia, 2017).

Scenario 3 shows the highest avoidance of green-house gases, environmental pollution and health risk compared to scenario 1 and scenario 2. Scenario 3 shows estimation that 50% of the waste has been landfilled, 25% of the waste has been recycled, 15% of the waste has been incinerated, and 10% of the waste has been composted. The rate of recycling in the country has been estimated to increase with the implementation of PPP and reduce the landfilling activity. PPP is a powerful economic instrument to support the waste management policy by increasing the waste separation and recycling among the consumer (Bilitewski, 2008). In Korea, the waste allocations have shifted from 1990 to 2008 due to implementation of the unit pricing system. 81.6% of the total waste has been disposed in the landfill in 1994 with low recycling rate at 15.36%. However, after implementation of unit pricing system, the recycling rate has increased steadily up to 59.8% in 2008 while landfill has decreased down to 20.3% (Korean Ministry of Environment, 2009).

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

This study was carried out to determine the contribution of polluter pays principle (PPP) on reduction of environmental pollution and health risk for municipal solid waste in Klang. In conclusion, the characteristics (i.e. volume, waste composition) of solid waste disposed in landfills from 2011 to 2017 were determined. The level of GHG emission (CH_4, CO_2), environmental pollution and health risk of the current practice (landfilling) was determined by using adopted mathematical equations. The level of GHG emission (CH_4, CO_2), environmental pollution and health risk of the of PPP scenario were determined and compared by using mathematical equation. It has shown that the volume of waste disposed in the landfill was increasing every year. Increase of waste disposed in the landfill will increase the emission of GHG, environmental pollution that can give risk to the health of the population. The implementation of PPP scenario has the potential to reduce the GHG emission and environmental pollution by enhancing recycle, incineration and composting as the alternatives to avoid landfilling practise. This scenario can reduce the impact of landfilling to the environment and human health.

6.2 LIMITATION

There are some limitations found during conducting of this study. Firstly, the estimation of methane gas only used Tier 1 default method based on mass approach. This method not very accurate compared to Tier 2 and 3 default method which based on First Order Decay (FOD). Furthermore, the scenarios created in this study did not accurately described the percentage of MSW that undergoes landfilled, recycled, composting and incineration. Next, the emission parameter of each disposal method (landfill, recycle, incineration, composting) cannot be all considered due to the different emission parameter. Other than that, the data sets for the current waste composition and current recycling rate in the country is not available, thus the data was taken from the previous study. The estimated concentration of non-methane organic compound (NMOC) in health risk assessment was not accurately calculated in the study.

6.3 RECOMMENDATION

Based on the findings from this study, there are several recommendations for the future research. Firstly, the greenhouse gases (CH_4, CO^2-eq), leachate volume, heavy metals in leachate datasets must be obtained from Jeram Sanitary landfill management as the current emission data. Other than that, the First Order Decay (FOD) model can be used to estimate the CH_4 and CO^2-eq emission from the landfills. The FOD is a model that provides a time dependent emission profile that reflects the pattern of waste degradation over time in the landfill. It assumes that the DOC of the waste will decay slowly overtime and will emit CH_4 and CO^2-eq to the atmosphere.

Furthermore, the receptor model can be used to estimate the concentration of non-methane organic compound at the landfill to obtain accurate reading for health risk assessment. As expected from the result, the current scenario shows the highest emission of greenhouse gases, leachate and heavy metal contain and emission of non-methane organic compound. Therefore, policy makers are advised to consider other alternative for municipal solid waste management in Malaysia to reduce environmental pollution and health risk among the population. Polluter pays principle need to be implemented in Malaysia by 2030 to achieve sustainable development goals that address the climate and environmental degradation and achieve a better and more sustainable future for the population.

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APPENDICES

APPENDIX I:

Household waste composition in Klang Valley

Table 1.0: Household waste composition in Klang Valley

Type of waste	Volume of waste (tonnes/year)							Statistic			
	2011	2012	2013	2014	2015	2016	2017	Min	Max	Mean	SD
Food waste	51,529.68	57,120.85	57,340.88	55,913.84	55,238.85	58,475.66	66,690.84	51,529.68	66,690.84	57,472.94	4634.308458
Plastics	13,609.42	15,086.09	15,144.21	14,767.31	14,589.04	15,443.91	17,613.61	13,609.42	17,613.61	15,179.08	1,223.96
Paper	10,934.06	12,120.45	12,167.14	11,864.34	11,721.11	12,407.93	14,151.10	10,934.06	14,151.10	12,195.16	983.35
Diapers	13609.42	15086.09	15144.21	14767.31	14589.04	15443.91	17613.61	13,609.42	17,613.61	15,179.08	1,223.96
Garden waste	6862.87	7607.52	7636.82	7446.76	7356.87	7787.95	8882.08	6,862.87	8,882.08	7,654.41	617.21
Glass	4071.19	4512.93	4530.32	4417.57	4364.24	4619.97	5269.03	4,071.19	5,269.03	4,540.75	366.14
Metal	2559.04	2836.70	2847.63	2776.76	2743.24	2903.98	3311.96	2,559.04	3,311.96	2,854.19	230.15
Textiles	4536.47	5028.70	5048.07	4922.44	4863.01	5147.97	5871.20	4,536.47	5,871.20	5,059.69	407.99
Tetra Pak	1628.48	1805.17	1812.13	1767.03	1745.70	1847.99	2107.61	1,628.48	2,107.61	1,816.30	146.46
Rubber	2442.72	2707.76	2718.19	2650.54	2618.55	2771.98	3161.42	2,442.72	3,161.42	2,724.45	219.69
Leather	348.96	386.82	388.31	378.65	374.08	396.00	451.63	348.96	451.63	389.21	31.38
Wood	1628.48	1805.17	1812.13	1767.03	1745.70	1847.99	2107.61	1,628.48	2,107.61	1,816.30	146.46
HHW	1744.80	1934.11	1941.56	1893.25	1870.39	1979.99	2258.15	1,744.80	2,258.15	1,946.04	156.92

Others	814.24	902.59	906.06	883.51	872.85	923.99	1053.81	814.24	1,053.81	908.15	73.23

Estimated based on Klang valley household waste compositions: Food waste (44.3%), Plastic (11.7%), Paper (9.4%), Diapers (11.7), Garden waste (5.9%), Glass (3.5%), Metal (2.2%), Textile (3.9%), Tetra Pak (1.4), Rubber (2.1%), Leather (0.3%), Wood (1.4%), Households hazardous waste (1.5%), Others (0.7%) (JPSPN, 2013)

APPENDIX II

Institutional, commercial and industrial waste composition in Klang Valley

Table 1.1: institutional, commercial and industrial waste composition in Klang Valley

Type of waste	Volume of waste (tonnes/year)							Statistic			
	2011	2012	2013	2014	2015	2016	2017	Min	Max	Mean	SD
Food waste	19,667.00	21,800.94	21,884.92	21,340.27	21,082.65	22,318.02	25,453.46	19,667.00	25,453.46	21,935.32	1768.75
Plastics	16,222.14	17,982.30	18,051.57	17,602.33	17,389.83	18,408.82	20,995.05	16,222.14	20,995.05	18,093.15	1,458.93
Paper	12,839.92	14,233.10	14,287.93	13,932.34	13,764.15	14,570.68	16,617.70	12,839.92	16,617.70	14,320.83	1,154.75
Diapers	501.07	555.44	557.58	543.70	537.14	568.61	648.50	501.07	648.50	558.86	45.06
Garden waste	1753.75	1944.03	1951.52	1902.95	1879.98	1990.14	2269.74	1,753.75	2,269.74	1,956.02	157.72
Glass	2004.28	2221.75	2230.31	2174.80	2148.55	2274.45	2593.98	2,004.28	2,593.98	2,235.45	180.25
Metal	3069.05	3402.06	3415.16	3330.17	3289.97	3482.75	3972.04	3,069.05	3,972.04	3,423.03	276.01
Textiles	1377.94	1527.45	1533.34	1495.18	1477.13	1563.68	1783.36	1,377.94	1,783.36	1,536.87	123.92
Tetra Pak	1879.01	2082.89	2090.92	2038.88	2014.27	2132.30	2431.86	1,879.01	2,431.86	2,095.73	168.99
Rubber	1002.14	1110.88	1115.16	1087.40	1074.28	1137.22	1296.99	1,002.14	1,296.99	1,117.72	90.13
Leather	313.17	347.15	348.49	339.81	335.71	355.38	405.31	313.17	405.31	349.29	28.16
Wood	939.51	1041.45	1045.46	1019.44	1007.13	1066.15	1215.93	939.51	1,215.93	1,047.87	84.49
HHW	688.97	763.73	766.67	747.59	738.56	781.84	891.68	688.97	891.68	768.43	61.96
Others	375.80	416.58	418.18	407.78	402.85	426.46	486.37	375.80	486.37	419.15	33.80

Malaysia Institutional, Commercial, and Industrial Waste Compositions: Food waste (31.4%), Plastic (25.9%), Paper (20.5%), Diapers (0.8), Garden waste (2.8%), Glass (3.2%), Metal (4.9%), Textile (2.2%), Tetra Pak (3.0), Rubber (1.6%), Leather (0.5%), Wood (1.5%), Households hazardous wasteb (1.1%), Others (0.6%) (JPSPN, 2013).

APPENDIX III

The emission of greenhouse gases (CH_4, CO_2) and environmental pollution of the current waste landfilling practice

Table 1.2 The emission of greenhouse gases (CH_4, CO_2) and environmental pollution of the current waste landfilling practice

	2011	2012	2013	2014	2015	2016	2017	Total	Min	Max	Mean	SD
Total volume of waste (tonnes/year)	178,953.56	198,370.71	199,134.85	194,179.00	191,834.85	203,075.74	231,605.63	1,397,154.34	178,953.56	231,605.63	199,593.48	16094.14294
GHG gases												
Methane (t)	7,760.57	8,602.62	8,635.76	8,420.84	8,319.19	8,806.66	1,0043.90	60,589.55	7,760.57	10,043.90	8,655.65	697.95
Carbon dioxide equivalent (t)	194,014.29	215,065.59	215,894.04	210,521.10	207,979.67	220,166.59	251,097.56	1,514,738.85	194,014.29	251,097.56	216,391.26	17,448.63
Leachate (m^3)	37,580.25	41,657.85	41,818.32	40,777.59	40,285.32	42,645.91	48,637.18	293,402.41	37,580.25	48,637.18	41,914.63	3,379.77
Heavy metals(kg)												
cadmium(Cd)	7.52E-02	8.33E-02	8.36E-02	8.16E-02	8.06E-02	8.53E-02	9.73E-02	5.87E-01	7.52E-02	9.73E-02	8.38E-02	0.01
chromium(Cr)	2.25E-01	2.50E-01	2.51E-01	2.45E-01	2.42E-01	2.56E-01	2.92E-01	1.76E+00	2.25E-01	2.92E-01	2.51E-01	0.02
copper (Cu)	1.88E-01	2.08E-01	2.09E-01	2.04E-01	2.01E-01	2.13E-01	2.43E-01	1.47E+00	1.88E-01	2.43E-01	2.10E-01	0.02
Lead (Pb)	5.64E-01	6.25E-01	6.27E-01	6.12E-01	6.04E-01	6.40E-01	7.30E-01	4.40E+00	5.64E-01	7.30E-01	6.29E-01	0.05
Zinc (Zn)	5.64E-01	6.25E-01	6.27E-01	6.12E-01	6.04E-01	6.40E-01	7.30E-01	4.40E+00	5.64E-01	7.30E-01	6.29E-01	0.05
NMOC (m^3)												
Acrylonitrile	3.76E-02	4.16E-02	4.18E-02	4.07E-02	4.03E-02	4.26E-02	4.86E-02	2.93E-01	3.76E-02	4.86E-02	4.19E-02	3.38E-03
Carbon disulfide	3.44E-03	3.81E-03	3.83E-03	3.73E-03	3.69E-03	3.90E-03	4.45E-03	2.69E-02	3.44E-03	4.45E-03	3.84E-03	3.09E-04
Carbon	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	2.65E-05	2.13E-06

tetrachloride												
Carbonyl sulfide	2.91E-03	3.22E-03	3.23E-03	3.15E-03	3.12E-03	3.30E-03	3.76E-03	2.27E-02	2.91E-03	3.76E-03	3.24E-03	2.61E-04
Chlorobenzene	1.48E-03	1.64E-03	1.65E-03	1.61E-03	1.59E-03	1.68E-03	1.92E-03	1.16E-02	1.48E-03	1.92E-03	1.65E-03	1.33E-04
Chloroethane	7.42E-03	8.22E-03	8.25E-03	8.05E-03	7.95E-03	8.41E-03	9.60E-03	5.79E-02	7.42E-03	9.60E-03	8.27E-03	6.67E-04
Chloroform	1.78E-04	1.97E-04	1.98E-04	1.93E-04	1.91E-04	2.02E-04	2.30E-04	1.39E-03	1.78E-04	2.30E-04	1.98E-04	1.60E-05
Dichloromethane	8.48E-02	9.40E-02	9.44E-02	9.20E-02	9.09E-02	9.63E-02	1.10E-01	6.62E-01	8.48E-02	1.10E-01	9.46E-02	7.63E-03
Ethylbenzene	2.73E-02	3.03E-02	3.04E-02	2.97E-02	2.93E-02	3.10E-02	3.54E-02	2.14E-01	2.73E-02	3.54E-02	3.05E-02	2.46E-03
Hydrogen sulfide (H2S)	2.11E-01	2.33E-01	2.34E-01	2.29E-01	2.26E-01	2.39E-01	2.73E-01	1.64E+00	2.11E-01	2.73E-01	2.35E-01	1.89E-02